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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

WASHINGTON MEETING

AT

WASHINGTON, D. C.

April 26–28, 1951

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AMERICAN PHYSICAL SOCIETY

1951 SPRING MEETING AT WASHINGTON, D. C., APRIL 26–28, 1951

THE **305th meeting of the American Physical Society,** being the 1951 Spring Meeting at **Washington, D. C.,** will be held on **Thursday, Friday, and Saturday, April 26th, 27th, and 28th,** 1951. We shall try a novel and a promising experiment. Of late years the Federal Government has provided us with various excellent halls, the only disadvantage being that the scientific sessions have been widely dispersed over Washington. This year we shall concentrate our meetings at the National Bureau of Standards and at two hotels—the Shoreham and the Wardman Park—so that all of the scientific sessions will be relatively close together, and a journey of a couple of miles up or down Connecticut avenue will be the most that will be imposed on anyone desiring to go from one session to another. In size (as measured by number of papers) this meeting will match the 1950 Washington meeting almost exactly. The Local Committee, as of recent years, is headed by Claire Marton and Hugh Odishaw, whose labors in the preparation of this meeting will have been enormous.

The **registration desk** will be located in the Hotel Shoreham. All members and guests are asked to register, and frequently to consult the bulletin board for notice of messages.

The **National Bureau of Standards** celebrates this year its semicentennial. Over and above its numerous distinctions as one of the major institutions of physics in the United States, it deserves the homage and the congratulations of our Society for a very special reason. The National Bureau of Standards and Columbia University have, each of them, granted their hospitality to the meetings of the American Physical Society more often by far than any other institution; and while Columbia has entertained us rather oftener than the Bureau, it is certain that the Bureau has received even more of our members than has Columbia—this is because, for thirty years or more, the annual Washington meeting was considerably larger than the annual New York meeting (and of late years it has been almost as large). We have been the guests of the Bureau in every year since 1905, apart from the years of World War II; it would be very fitting if on this occasion we could do something very special for the Bureau staff to show our gratitude, but instead we must show it by accepting their hospitality once again, like a child who buys a Christmas present for his parents with their money. On Friday, in the East Building Lecture Hall, there will be a full-day programme of invited papers descriptive of some of the many facets of the work of the National Bureau of Standards; and its Director will be our honored and welcome after-dinner speaker at the banquet.

In addition to the Bureau symposium there will be **two other symposia** on the general programme: one on the **services rendered to physics by computing machines,** this to be held on Saturday morning; and one on **stable isotopes,** this to be held on Friday morning. On Thursday afternoon we shall hear two distinguished foreign physicists, A. Scheibe (President of the Physikalisch-Technische Bundesanstalt, who will describe the work and the plans of his institution), and W. Ehrenberg who will speak on semiconductors. On Saturday morning there will be a group of three invited papers by W. Barkas (mesons), R. B. Leighton (V-particles), and S. A. Goudsmit (precision measurements with a new mass-spectrograph).

Our **Division of High-Polymer Physics** (to which the Secretary here apologizes for his failure to mention its sessions on the summons card) will hold two symposia: one on Thursday morning under the title "Transitions in Polymers," the other on Thursday afternoon under the title "The Relative Effects of Frequency and Temperature on Dynamic Mechanical Properties." Other invited and contributed papers in high-polymer physics will be presented on Friday morning and a few on Friday afternoon.

Two hundred and eighty-three ten-minute papers (including those of the Division of High-Polymer Physics) are distributed among twenty-five sessions.

The **banquet of the American Physical Society** will be held on Friday evening at seven in the Terrace Room of the Hotel Shoreham. The after-dinner speakers will be E. U. Condon, Director of the National Bureau of Standards, and A. T. Waterman, Director-Nominate of the National Science Foundation. The price of the dinner will be five dollars. Use the form on the inside back-cover page of this Bulletin for advance reservation; we ought to be able to give the hotel by the first day of the meeting a reasonable estimate of the number of diners to be expected. The tickets will be on sale at the registration desk; and the Society reserves the right to sell uncalled-for and unpaid-for tickets to the first comers after three o'clock on Friday afternoon.

The Director of the National Bureau of Standards and Mrs. E. U. Condon will entertain the members and guests of the Society at tea in their home on the Bureau grounds from 4:30 to 6:00 on Thursday afternoon.

A luncheon for the ladies attending (or whose husbands are attending) the meetings will be arranged by Mrs. F. G. Brickwedde. It will be held on the Friday at 12:45 in the restaurant Napoleon (2649 Connecticut Avenue), and tickets at $1.60 or thereabouts will be on sale at the registration desk until 10:00 on Friday morning. There is also a tour of several Embassies on Saturday afternoon; this is not an affair of the Society, but tickets may be bought for it at another desk in the Shoreham lobby.

The Sigma Pi Sigma luncheon will be held on Friday at 12:30 P.M. in the Tilden Gardens Hotel dining room, on Connecticut Avenue just south of the Bureau. Tickets at $1.75 will be on sale at the registration desk until 10:00 on Friday morning, and should be reserved in advance by letter to Dr. Marsh W. White, Osmond Laboratory, Pennsylvania State College, State College, Pennsylvania.

The **Council** of the American Physical Society will meet on Thursday at 10:00 A.M. in the Conference Room of the South Building of the National Bureau of Standards, unless a contrary notice is distributed to its members.

The **Nominating Committee** of the American Physical Society will meet on Friday at 4:30 P.M. in the Conference Room of the South Building of the National Bureau of Standards. This Committee consists of I. I. Rabi (Chairman), W. Bleakney, J. B. Fisk, W. A. Fowler, S. A. Goudsmit, L. J. Haworth, R. G. Herb, M. L. Huggins, and J. C. Slater.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to the supplementary programme if the abstracts are received at the office of the Society not later than Friday, April 20. The abstracts of such post-deadline papers as are accepted will not be printed; the titles will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session Z.

Representatives of government laboratories will be available for employment interviews in a foyer adjoining the West Ballroom of the Shoreham Hotel.

Prospective meetings of the Society are scheduled for Schenectady, June 14–16 (deadline will be April 28); Vancouver, B. C., June 25–28; Chicago, October 25–27 (joint meeting with the American Institute of Physics and the other Founder Societies), and Houston, November 23–24.

General Rules for Presentation of Papers

The time allowed for the oral presentation of a contributed paper is ten minutes at most. The time allowed for the presentation of each invited paper is stated in the Bulletin.

When two or more contributed papers are submitted by the same member, all but one are placed on the "supplementary programme." (A paper by two or more members is credited, for this purpose, to the first person named on its by-line.) For each paper on this programme a session is indicated, at the end of which it may be offered; but the Chairman is empowered to require that it be given in fewer than ten minutes, or to read it by title.

Titles and abstracts of the papers contributed to the 1951 Washington meeting are printed hereinafter, exactly as they will stand in a future issue of *The Physical Review*. Errata will be printed on an adjacent page of *The Physical Review* if received not later than Friday, May eleventh, by Miss Ruth Bryans, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections; write out the corrections in the form "instead of .... read ....". Do not add new results.

Speakers must retrieve their lantern slides before leaving the hall in which they gave their papers. The Local Committee must not be burdened with the task of saving and returning them.

Karl K. Darrow, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards.)

Thursday Morning

A. Cosmic rays, mainly showers and stars. Shoreham, Main Ballroom.
B. Ultrasonics and fluid dynamics. Shoreham, West Ballroom.
C. Electrical phenomena in gases; cryogenics. NBS, Materials Testing.
D. Reactions of transmutation, H through Be. Shoreham, Terrace Room.
E. Symposium of the Division of High-Polymer Physics: Transitions in Polymers; Fox. NBS, East Building.

Thursday Afternoon

EA. Symposium of the Division of High-Polymer Physics: The Relative Effects of Frequency and Temperature on Dynamic Mechanical Properties. Tobolsky, Ferry, de Witt, Marvin, Nolle, Sack. NBS, East Building.
F. Production and capture of mesons and electron pairs. Shoreham, Main Ballroom.
G. Ferromagnetic substances. Shoreham, West Ballroom.
H. Microwave spectra and magnetic resonance. Wardman Park, Continental Room.
I. Scheibe, Ehrenberg. NBS, Materials Testing.
J. Reactions of transmutation, boron onwards; electron capture. Shoreham, Terrace Room.

Friday Morning

JA. Division of High-Polymer Physics; Codrington *et al.*, contributed papers. NBS, Materials Testing.
K. Radioactive nuclei, tritium through cerium; neutrinos. Shoreham, West Ballroom.
L. Symposium on stable isotopes: Keim, McNally, Pool-Kundu, Nier. Shoreham, Main Ballroom.
M. Scattering. Wardman Park, Continental Room.
N. Metals. Shoreham, Terrace Room.
P. Work of the National Bureau of Standards, Part I: Astin, Huntoon, Fano, Meggers, Pellam, McNish. NBS, East Building.

Friday Afternoon

PA. Work of the National Bureau of Standards, Part II: Curtiss, Slutz, Gardner, McMurdie, Schubauer, Cook. NBS, East Building.
Q. Radioactive nuclei beyond cerium. Shoreham, West Ballroom.
QA. General theory. Wardman Park, Continental Room.
R. Crystals and semiconductors. Shoreham, Terrace Room.
RA. Nuclear masses, abundances and magnetic moments. Shoreham, Main Ballroom.
S. High-polymer physics and biophysics. NBS, Materials Testing.

Friday Evening

Banquet of the American Physical Society. Shoreham, Terrace Room. Waterman, Condon.

Saturday Morning

SA. Apparatus of nuclear physics; Bremsstrahlung, Shoreham, Terrace Room.
T. Neutrons; fission. Wardman Park, Continental Room.
U. Physical problems solved by computing machines: Pepinsky, Thomas, Wheeler-Hill, Spencer, Alpher-Herman. NBS, East Building.
V. Barkas, Leighton, Goudsmit. Shoreham, Main Ballroom.
W. Nuclear theory, I. Shoreham, West Ballroom.

Saturday Afternoon

WA. Nuclear theory, II. Shoreham, West Ballroom.
X. Counters and counting circuits. Shoreham, Main Ballroom.
Y. General physics. NBS, East Building.
Z. Optical spectroscopy. Shoreham, Terrace Room.

PROGRAMME

THURSDAY MORNING AT 10:00

Shoreham, Main Ballroom

(R. B. LEIGHTON presiding)

Cosmic Rays, Mainly Showers and Stars

A1. Low Energy Spectrum of Heavy Primary Cosmic Rays. H. L. REYNOLDS,* D. M. RITSON, AND E. P. WOODRUFF, *University of Rochester.*—A series of measurements have been made on two stacks of plates flown at geomagnetic latitude 55° to determine the energy spectrum of the heavy primary radiation down to energies corresponding to the geomagnetic cutoff. The stacks consisted of photographic plates interspersed with absorber, one stack reaching an altitude of 110,000 feet. Energies and charge were determined from simultaneous range and δ-ray or grain counts in insensitive plates. The range covered is from 10 to 80 grams per cm². Detailed flux data resulting from this work will be presented. This work was performed under the joint program of the AEC and ONR.

* AEC Predoctoral Fellow.

A2. Nature of the Soft and Hard Component of the Cosmic Radiation Close to the Top of the Atmosphere.* M. VIDALE AND MARCEL SCHEIN, *University of Chicago.*—Data will be presented in which the vertical intensity of the cosmic radiation traversing 0, 4, 7.5, and 12 cm of lead was determined as a function of latitude and altitude. The data were obtained through the courtesy of ONR, with the aid of General Mills balloons which were flown at 28°N, 41°N, and 55°N geomagnetic latitude. The rate of ascent was very slow in most of the flights (down to 150 ft/min), so that accurate measurements of the intensity of the various cosmic-ray components could be obtained in the stratosphere up to altitudes of 94,000 ft. The soft component shows a very small latitude effect between 41°N and 55°N in the neighborhood of its maximum, whereas the hard component shows a large effect at these altitudes. This fact strongly indicates that the soft component at these altitudes originates predominantly from neutral mesons[1] which are produced abundantly in the cosmic radiation only at energies greater than 4 Bev (cut-off energy at 41°N).

* Assisted by the joint program of the ONR and AEC.
[1] B. Rossi, Revs. Modern Phys. **20**, 537 (1948).

A3. Structure of the Soft Component at Low Altitudes. E. D. PALMATIER,* *Cornell University.*—Telescopes constructed from thin-walled aluminum Geiger counters were used to determine the absolute intensity of the total radiation as a function of zenith angle, altitude, and minimum energy of the particles. Studies were conducted of the various errors associated with such measurements, particularly those arising from counter wall phenomena and extensive showers. The soft component intensity for various energy bands was obtained in the usual manner from the corrected total intensities by subtraction of the hard component.[1] It is apparent that the electronic radiation at low altitudes does not possess a simple structure but can be divided into two components as follows: (a) E_m component—comprising about 70 percent of the electronic component at Ithaca and 40 percent at Echo Lake and agreeing in altitude variation and in intensity with that predicted on the basis of meson knock-ons and of decay electrons arising from a three particle mu meson decay. (b) E_s component—very energetic and possessing very steep altitude and zenith angle dependences similar to the N component.

* Now at the University of North Carolina, Chapel Hill, North Carolina.
[1] W. Kraushaar, Phys. Rev. **76**, 1045 (1949).

A4. A Dual Cloud Chamber Study of Extensive Air Showers.* G. M. BRANCH, *Cornell University.*—The nature of penetrating particles in extensive air showers was investigated with a dual cloud chamber assembly during the summer and fall of 1949 at Echo Lake, Colorado. Two rectangular cloud chambers of dimensions 24″×12″×12″, each containing five ¼″ Pb plates, were placed one above the other and separated by a 6″ layer of lead. The chambers were expanded simultaneously for incident air showers containing one or more penetrating particles as detected by extension counter trays near the apparatus and shielded trays between the chambers. The photographs obtained demonstrate the existence of nuclear cascades contributing to the successive development of the electronic component in air showers. About 40 percent of the charged penetrating component in air showers is found to be strongly interacting, in qualitative verification of the interpretation of recent shielded counter experiments. Also, 80 percent of the nonlocally produced associated penetrating particles in the lower chamber are observed to have angular deviations of less than 3° from their respective air shower axes, corresponding to momenta greater than 2 Bev/c. Representative photographs showing the complex nature of air showers will be presented.

* Supported in part by a grant from the Research Corporation.

A5. Cloud-Chamber Observations of Forked Tracks in Penetrating Showers.* R. W. THOMPSON, HANS O. COHN, AND R. S. FLUM, *Indiana University.*—Examples of the forked tracks previously reported[1,2] have been obtained in a sea-level experiment designed to study penetrating showers. A 12-inch diameter magnet cloud chamber below 4 inches of lead is triggered by an array of counters which responds preferentially to events in which two or more penetrating particles are produced in the lead above the chamber. Stereoscopic photographs of forked tracks of the inverted V-type have been obtained under conditions which permit determination of the charge and momentum of the visible particles and the angle between the tracks. The experiment is in progress and the results of these measurements will be reported.

* Assisted by a grant from the Frederick Gardener Cottrell Fund of the Research Corporation.
[1] G. D. Rochester and C. C. Butler, Nature **160**, 855 (1947).
[2] Seriff, Leighton, Hsiao, Cowan, and Anderson, Phys. Rev. **78**, 290 (1950).

A6. Electron Showers and Sprays at High Altitude. SOPHIE OLEKSA, E. P. NEY, AND C. L. CRITCHFIELD,* *University of Minnesota.*—A Wilson cloud chamber with four vertical ¼″ Pb plates was flown at 90,000 feet in Minnesota, 55°N magnetic latitude. The pictures were examined for electron showers having ten or more particles at shower maximum (≥1-Bev showers) and for "spray" events of more than six prongs. The criteria were the same as those employed in the investigation of these phenomena in horizontal plates flown under the same

conditions.[1] The flux of cascade generating radiation is about three times greater for the vertical plates than for the horizontal plates. Presumably this arises from multiplication of the soft component in the longer average path near the horizon. If spray-producing radiation is effective in the same solid angle as that for showers, its flux appears to be greater also for horizontal directions. The possibility that sprays are cascades[2] implies a rather complicated geometrical factor, however, and the results are being analyzed.

* Work assisted by joint program of the ONR and AEC and by a grant from the Graduate School of the University of Minnesota.
[1] Critchfield, Ney, and Oleksa, Phys. Rev. **79**, 402 (1950).
[2] R. R. Rau, Phys. Rev. **80**, 914 (1950).

A7. The Dependence of Star Production Rates on Absorbers and Altitude. HARRIET H. FORSTER, *University of Southern California.*—The photographic technique has been used to investigate the effect of absorbing material on the rate of star production. Photographic plates, mainly Ilford C2 emulsions and Kodak minimum ionization plates 100μ thick and shielded with lead and paraffine have been exposed at sea level and at altitudes of 10,000 and 30,000 ft, respectively. The plates were placed horizontally and surrounded on all sides by sheets of absorbing material so that the absorber thicknesses were 11.3, 17, 22.6, 33.9, and 56.5 g/cm^2 in the case of lead and 1.5, 3.5, 7.2, and 15.3 g/cm^2 in the case of paraffine. With each set of plates surrounded by absorbing material, plates without absorber were exposed simultaneously. A comparison of the rates of star production in the different sets yields a distinct transition effect for lead; for paraffine no such effect has been observed for the thickness of absorber employed. Data concerning the magnitude of the transition effect and its dependance on altitude will be shown and the results discussed with relation to the work by other authors on stars and penetrating showers.

A8. The Stars Initiated by Synchrotron Gamma-Rays.* SEISHI KIKUCHI, *Cornell University.*—The results of an analysis of stars as well as of single tracks recorded in photographic emulsions exposed to a beam of synchrotron gamma-ray beam of maximum energy of 300, 250, 200, and 150 Mev will be reported. Both C2 and G5 emulsions were used. The excitation curve for star production is quite similar to that of meson production. The cross sections in millibarn per equivalent quantum obtained at above-mentioned energy values are 6.04±0.41, 5.62±0.56, 2.55±0.19 and 1.95±0.18, respectively. About five percent of the stars are associated with a meson track of varying energies. These results seem to show that the stars are produced by π-meson created in the interior of the nucleus followed by the collision with or the absorption by the nucleon in the same nucleus as it is produced. The number of single tracks at 300-Mev excitation is about twice the number of stars. The number of protons coming out of stars is about twice that of single proton tracks. The energy distribution and angular distribution of these protons as well as alpha-particles are studied.

* This work was performed under contract with the ONR.

A9. Meson Production in Cosmic-Ray Stars of Very High Energy.* MARCEL SCHEIN AND J. J. LORD, *University of Chicago.*—Very high energy nuclear interactions were observed in Ilford G5 emulsions exposed at elevations greater than 90,000 ft. A study was made of a proton collision with a silver nucleus in which 95 charged particles were emitted. The number of the charged mesons produced was determined from conservation of charge considerations of all emitted tracks. It was found that at least 55 tracks of minimum ionization must be due to mesons and 11 to high energy protons. The star had a very narrow core of minimum ionization particles which were emitted within half-width of 0.01 of a radian. The energy of the incident proton was estimated to be 3×10^{13} ev. The mechanism of this nuclear collision favors multiple meson production from the first nucleon-nucleon collision.[1] It is assumed that these mesons can give rise to the production of additional mesons in subsequent collisions in the same nucleus.[2] Similar events produced by α-particles and heavy nuclei will be discussed. The absolute frequency of occurrence of stars with energies greater than 10^{12} ev strongly indicates that the primary spectrum does not fall off as fast as it has previously been assumed for $E>10^{12}$ ev.

* Assisted by the joint program of the ONR and AEC.
[1] E. Fermi, Prog. Theor. Phys. **5**, 570 (1950).
[2] W. Heitler and L. Janossy, Helv. Phys. Acta **23**, No. 4, 417 (1950). L. S. Osborne, Phys. Rev. **81**, 239 (1951).

A10. Transition Effect in Pb of the Star-Producing Radiation in the Stratosphere. M. M. SHAPIRO, M. BIRNBAUM, F. W. O'DELL, AND B. STILLER, *Naval Research Laboratory.*—Behavior of the *N*-component of the cosmic rays in Pb at a mean atmospheric depth of 2 cm Hg and geomagnetic latitude 55°N was explored by measuring star frequency *versus* depth in an absorber which spent 7 hours above 3 cm Hg in a balloon flight. Vertical orientation of 400μ Ilford G5 emulsions inside a "canyon" in the Pb permitted detailed investigation of the transition curve. Observation of 3000 stars ($\geq$3 pronga) yields these tentative conclusions: the frequency of *large* stars ($\geq$6 "gray" and black tracks) first increases with depth, saturates between 25 and 60 g/cm^2, then drops gradually toward 155 g/cm^2. There are indications of two peaks in the region of saturation, with maxima near 25 and 60 g/cm^2. *Small* stars show similar, but less pronounced, characteristics. They differ, however, in two features: an initial drop to $\approx$15 g/cm^2, and a general upward trend which extends to depths $\approx$70 g/cm^2. Results will be compared with those of other workers.[1]

[1] J. J. Lord and M. Schein, Phys. Rev. **75**, 1956 (1949). Blau, Nafe, and Bramson, Phys. Rev. **78**, 320 (1950).

A11. Study of Nuclear Explosions Using a Cloud Chamber Containing a NaI Crystal.* G. SALVINI AND GEO. T. REYNOLDS, *Princeton University.*—A general difficulty of GM counter and cloud-chamber cosmic-ray experiments measuring high energy nuclear cross sections is that the probability of detecting the nuclear events depends on the number and angular spread of the relativistic particles and on the distribution of the energy between nuclear particles and the electromagnetic component (neutral mesons). To avoid this difficulty a cloud chamber (18″×18″×8″) has been prepared containing a large NaI crystal, viewed by photo-multipliers outside the chamber. The evaporation products of nuclear explosions in the crystal furnish the signal that triggers the chamber. This allows an unbiased study of the relativistic particles and the electromagnetic component arising from the explosions. Plates of carbon and lead were used in the chamber. Preliminary measurements have been made of (1) the mfp in carbon of the relativistic particles emitted in the explosions and (2) the electromagnetic component emitted in order to compare the probabilities of charged and neutral mesons in these high energy interactions. The performance of the cloud chamber and the results at sea level will be discussed.

* Supported by the joint program of the AEC and ONR.

A12. A Cloud-Ionization Chamber for the Study of Cosmic-Ray Nuclear Interactions.* H. W. LEWIS, W. W. BROWN, D. O. SEEVERS, AND E. W. HONES, *Duke University.*—A combination cloud chamber and ionization chamber in which the gas (argon at 51 lb in^{-2} saturated with iso-amyl alcohol) is common to both chambers is described. The ion chamber, a 3$\frac{1}{4}$-in. diameter brass cylinder 8 in. in length open at both ends and having a $\frac{1}{8}$ in. central wire, is mounted coaxially with the cloud chamber, which has a useful rectangular volume 10 in.×10 in.×8 in. A burst occurring in the ion

chamber generates a pulse which is used to trigger the expansion mechanism. Rapid reduction of the cylinder voltage from −1800 volts to ground, after electron collection is over, prohibits any appreciable motion of positive ions and thus permits observation of the tracks of the burst producing particles. In preliminary tests at sea level, cosmic-ray bursts from cascade showers and from stars occurring in the wall (up to 10 prongs) and in the gas (up to 5 prongs) of the ion chamber have been observed.

* This work was supported by the joint program of the ONR and AEC.

A13. Spectrum and Path Length for Nuclear Interaction of Cosmic-Ray Protons.* CHARLES E. MILLER, JOSEPH E. HENDERSON, D. S. POTTER, AND J. TODD, JR., *University of Washington.*—A magnetic cloud chamber was used to photograph those charged particles stopping in 15 and 30 cm of lead placed just below the chamber. Because of nuclear interactions the 30 cm of lead absorber is sufficient to stop almost all protons even at energies above 1 Bev as well as the secondary products of their nuclear collisions. As mesons show ionization energy loss only, all those of sufficient range emerge from the absorber block and actuate one of the anticoincidence counters completely surrounding it. The distribution in momentum of negatively charged particles photographed in this way shows a rapid cut-off above the momentum corresponding to the range of μ-mesons for the absorber thickness used while the corresponding intensity of positive particles is still large at momenta of 2 Bev/c. The pos.-neg. difference at momenta well above the meson cutoff is taken to represent protons. This data along with previous observations is sufficient to determine both the spectrum and nuclear path length (path length for removal) of protons. The nuclear path length in lead for protons of 0.5–1.0 Bev is found to be about 160 g/cm^2.

* Assisted by the joint program of the ONR and AEC.

THURSDAY MORNING AT 10:15

Shoreham, West Ballroom

(H. L. DRYDEN presiding)

Ultrasonics and Fluid Dynamics

B1. Ultrasonic Absorption in Some Halogenated Methylenes, Ethanes, and Ethylenes. DANIELE SETTE, *Istituto Nazionale di Ultracustica, Rome.**—In order to get information about the influence of the structure of liquids on elastic relaxation, measurements of ultrasonic absorption were performed in eight organic halides, in the temperature range 40°C, −20°C. A pulse method was used at 30 Mc/sec. In the methylene series the absorption coefficient has high values and decreases in the order: chloride, bromide, iodide. The temperature coefficient is positive. In a series of dichloroethane, while the absorption coefficient of 1,1 dichloroethane increases with the temperature, the coefficients of 1,2 dichloroethane and of 1,2 dibromoethane decrease when the temperature rises. Moreover, the absorption is larger in the bromothan in the chloro-substitute. For *cis*-dichoroethylene the value of α/ν (α amplitude abs. coeff, ν frequency) at 20°C, is 540 10^{17}, for *trans*-dichloroethylene it is 356 10^{17} sec^2/cm. The absorption increases with temperature, for both liquids. These results indicate that the ultrasonic absorption is largely dependent on the structure of liquids and on the characteristics of the short range forces among neighboring molecules. It seems, besides, that the dipole moment often does not have a direct importance on the phenomena, except in fixing the relative position of molecules.

* Work done with the help of a grant of Italian Research Council, at the Catholic University of America, Washington D. C., aided by ONR contract.

B2. Intensity Dependence of the Coefficient of Absorption of Ultrasonic Waves.* FRANCIS E. FOX, *Catholic University of America.*—It has been observed that the amplitude coefficient of absorption (α) of continuous ultrasonic waves in water increases for intensities above 0.05 watt/cm^2. It has been suggested that this is caused by cavitation, although visible cavitation appears only at much higher intensities. Since cavitation, in general, should lead to an increase in the absorption coefficient; measurements of α as a function of the intensity I should yield data for testing cavitation theories, as well as general theories of the liquid state. α was measured at 10 mc in out-gassed water, water saturated with air, and water saturated with CO_2, and at 5 mc in CCl_4, for intensities as high as 5 watts/cm^2. The values of α_1/α_0 are given for comparison, where α_1 is the absorption coefficient at 1 watt/cm^2 intensity, and α_0 is the low intensity α: air free water −2.7; water saturated with air −2.7; water saturated with CO_2 −2.2; CCl_4 −1.25.

* Work assisted by ONR contract.

B3. Dispersion and Absorption of Ultrasonics in Nitrogen.* ALFRED JOSEPH ZMUDA, *Catholic University of America.*—By means of the interferometer, the velocity and absorption of ultrasonic waves in nitrogen were measured at the frequency of 2.992 mc/sec, in the pressure range of 2.09 to 76 cm of Hg at a temperature of 29°C. A dispersion of velocity was found ranging from 354.3 meters/sec to 364.4 meters/sec. The ratio ($\alpha_{exp}/\alpha_{class}$) dropped from 1.40 to 1.32, and the corresponding value of C_v/R dropped from 2.50 to 2.08. The increase in velocity and the decrease in ($\alpha_{exp}/\alpha_{class}$) is interpreted as owing to the slow exchange of energy between the translational and rotational degree of freedom. The relaxation time for the rotation was found to be 1.2×10^{-9} sec.

* Work supported by the ONR.

B4. A Statistical Mechanical Approach to Turbulence. WILLEM V. R. MALKUS, *University of Chicago.*—The lack of uniqueness in solutions of hydrodynamical equations applicable to open systems necessitates the search for a criterion to determine the most probable solution. The phrase "most probable" can have meaning in the statistical mechanical sense of the *a priori* probability of a quasi-ergodic ensemble. One might hope to obtain a most probable solution by maximizing the *a priori* probability of the velocity distribution function averaged over space and time and constrained both by macroscopic continuity relations and by boundary conditions. A less general method would be to compare several given steady state, or mean, velocity distributions to determine their respective probabilities as a function of such parameters as these distributions may contain. As one aspect of such problems, the flow between parallel plates and in pipes is considered. The probability of the laminar motion is compared with that of an arbitrary mean motion. A variational optimiza-

tion of the arbitrary motion permits the establishment of a criterion for the onset of turbulence and determines the momentum transport to the walls as a function of the mean velocity. The results obtained are compared with the empirically established relations.

B5. The Model Firing Range: A Pressurized Range for Small Caliber Projectiles in Free Flight. V. E. BERGDOLT, A. J. GREENWALD, AND D. B. SLEATOR, *Aberdeen Proving Ground.*—The small pressurized range has been developed to study experimental flows about projectiles in free flight at Mach numbers up to 4 and at air densities attainable at pressures up to 30 atmospheres. Outside the range, at a set of windows, the flow field is observed with a Mach-Zehnder interferometer. Since the effective duration of the source is relatively long, a rotating mirror-camera system is used to stop the projectile on the film. Investigations in the source size theory of the Mach-Zehnder interferometer have shown that the best fringes are formed perpendicular to the plane of centers of the optical elements. To satisfy this criterion, the interferometer has been modified so that the plane of centers is vertical and the fringes horizontal. The recent development of the monochromator light source and the reorientation of the interferometer have resulted in interferograms of consistently good quality. The effect of increased air density is apparent in the comparison of fringe shift patterns for the same projectile at range pressures up to 5 atmospheres.

B6. Monochromatic Light Source for Interferometry of High Speed Gas Flows. D. B. SLEATOR, V. E. BERGDOLT, AND F. D. BENNETT, *Aberdeen Proving Ground.*—Interferometry of air flows about supersonic projectiles requires a high intensity light source with short duration and a high degree of monochromaticity. It is shown that a BH6 mercury flash tube and liquid prism monochromator together produce a satisfactory solution to the problem. Conventional glass filters fail because of excessive breadth of pass band; while interference type filters impose excessive requirements on intensity and collimation of the light. Analysis is given of the problem of maximizing light transmission through the monochromator, and the design of a liquid prism instrument employing CS_2 refractive medium is discussed. Finally, comparison of interferograms shows the improvement achieved over a conventional Wratten filter.

B7. Experimental Verification of Source Size Theory for the Mach-Zehnder Interferometer. G. D. KAHL AND F. D. BENNETT, *Aberdeen Proving Ground.*—The simplified theory of the Mach-Zehnder interferometer developed by the latter author is tested. The reduction in the visibility of fringes formed by the interferometer owing to an extended area light source is shown experimentally. This reduction is shown to be caused by the superposition of two separate effects which are characteristic of the two angular coordinates of the unit vector pointing from the center of the collimating lens toward each point in the plane of the area-type source. The relation of each of the effects to that coordinate characterizing it is demonstrated experimentally to agree with the theory. The result of combining these two effects from all of the points of an area-type source is seen experimentally to cause the "focusing" of the visible fringes, and to limit them to a finite region of the intersecting beams determined by the size and shape of the source.

B8. Effect of Random Errors in Fringe Shift on Interferogram Reductions of Axi-symmetric Flows. F. D. BENNETT, *Aberdeen Proving Ground.*—A description of the adaptation to Eniac computation of the equation for density ratio $(\rho/\rho_0)_i$ in terms of fringe shifts for an interferogram of an axi-symmetric flow has previously been given.[1] On the hypothesis that the disturbance be divided into N zones of equal radial increment w, a simple expression can be derived connecting the rms error Σ_i of the density ratio with the rms error σ_j of fringe shift at each zone. Further simplifications are possible if $\sigma_j = \sigma$ for all j with the result that a bound for Σ_i may be obtained which varies as $[w(2r_i+w)]^{-\frac{1}{2}}$. Data from interferogram reductions are presented and comparison is made between apparent random errors in the $(\rho/\rho_0)_i$ values and those predicted by the bound on Σ_i.

[1] Phys. Rev. **76**, 880A (1949).

B9. Electrical Properties of Detonation Shocks. J. SAVITT AND R. H. F. STRESAU.—In detonation velocity measurements, time signals are frequently obtained from probes which are connected electrically by the ionized gases of the shock front. Since the accuracy of time measuring devices is frequently affected by the nature of the electrical signal received from such probes, measurements have been made of the electrical properties of the ionized paths. The apparatus consist of a condenser, the probe, a vacuum thermocouple, and a fluxmeter or peak micro voltmeter. The condenser is discharged through the heater of the vacuum thermocouple, and the energy delivered can be determined either from the peak voltage at the thermocouple terminals or from the voltage-time integral as measured by a fluxmeter. The apparatus is calibrated using a switch of proven negligible loss. When the probe is substituted for the switch, the difference between the reading obtained and the calibration is interpreted as the loss at the probe. By determining this loss as function of voltage, capacitance, and thermocouple heater resistance, the electrical properties of the ionized gases in the gap may be studied. Measurements have been made of these properties as functions of the relative position of the explosive charge and the probes.

THURSDAY MORNING AT 10:15

NBS, Materials Testing

(W. P. ALLIS presiding)

Electrical Phenomena in Gases; Cryogenics

C1. Formation of Metallic Arcs.* G. F. HULL, JR., AND J. W. MEYER, *Dartmouth College.*—When metallic contacts carrying a current are separated, the contact may be bridged by a small globule of metal, following which an arc may be formed. Cathode-ray oscillograms of the voltage across separating contacts have been obtained for twenty different metals ranging from Sn to W. These oscillograms show a rise in voltage first to the melting point of the metal and a second rise to the boiling point before the arc strikes. For the metals investigated, the voltages at the melting and boiling points agree within a few percent with those predicted theoretically. From the oscillograms, minimal length arc characteristics for gold and

platinum have been obtained. Examination of all the oscillograms which contain arcs (several thousand) shows that an arc is always preceded by the formation of a metallic bridge. Further investigation of arcs formed by exploding small wires of the same dimensions as bridges shows that the wire is first melted and then vaporized before the arc strikes. Calculation shows that the energy expended in vaporizing and ionizing the vapor of the small wire corresponds to the energy expended in producing the minimal length arc.

* Assisted by the ONR.

C2. Measurement of Electron Temperatures in a Pulsed, Electrodeless, Toroidal Discharge Tube. W. H. BOSTICK, W. W. STRIKER, AND M. F. GROVER, *Tufts College.*—An electrodeless, gaseous, toroidal discharge tube threaded by an energized pulse transformer core gives a fairly bright pulsed excitation of the gas for pressures from 1000 down to 15 microns. A small probe, connected to ground through a resistance and protruding into this discharge, will attain either positive or negative potentials (up to 1000 volts) depending upon the particular conditions of the discharge. It is inferred that under certain conditions electrons in the plasma become fairly well separated from the positive ions and are then almost totally responsible for the negative potential attained by the probe. A measurement of probe current and voltage then enables one to measure electron temperatures of 10^6 degrees Kelvin for a distribution which appears to be maxwellian.

C3. Recombination between Electrons and Atomic Ions. MANFRED A. BIONDI, *Westinghouse Research Laboratories.*—Values of electron-ion recombination coefficients have been reported[1,2] which are from 10^3 to 10^5 times larger than those predicted by quantum theory for radiative capture of an electron by an ion. The present investigation is directed at determining the capture mechanism responsible for these large recombination coefficients. In low pressure helium (0.5 mm–3 mm Hg), it is found that atomic lines are emitted in the afterglow, in contrast to the observations of Johnson *et al.*[2] for higher pressures (10–30 mm Hg) where molecular bands were observed. Absolute intensity measurements show that for each electron lost by recombination, roughly one quantum of visible radiation is emitted. The observed lines originate from high lying states ($n=4$, 5, 6) which are all less than 1.5 volts below ionization potential. These results are difficult to reconcile with Bates' suggestion[3] of dissociative recombination of electrons with He_2^+ ions, since the dissociation energy of the latter is undoubtedly greater than 1.5 ev.

[1] M. A. Biondi and S. C. Brown, Phys. Rev. **76**, 1697 (1949).
[2] Johnson, McClure, and Holt, Phys. Rev. **80**, 376 (1950).
[3] D. R. Bates, Phys. Rev. **77**, 718 (1950).

C4. Transfer of Excitation in Atomic Collisions. T. HOLSTEIN AND IRA B. BERNSTEIN, *Westinghouse Research Laboratories.*—The cross section for the transfer of excitation in a collision between two atoms is calculated under the assumptions that only two states of the compound system are involved, and that the nuclear motion can be treated classically, i.e., prescribed as a function of time. These assumptions lead to a system of two coupled first-order linear differential equations for the transition amplitudes. The argument here is the time, as opposed to the internuclear separation which appears in the pair of second-order equations of previous quantum-mechanical treatments of the problem.[1,2] The cross section is then determined, either rigorously or approximation-wise, depending on the various assumptions as to the interaction. The results, which yield the expected resonance cross section and demonstrate exponential decrease for increasing deviation from resonance, are compared with those of Stueckelberg.[3]

[1] F. London, Z. Physik **74**, 143 (1932).
[2] E. C. G. Stueckelberg, Helv. Phys. Acta **5**, 369 (1933).

C5. Imprisonment of Resonance Radiation in Sodium Vapor. A. O. MCCOUBREY, D. ALPERT, AND T. HOLSTEIN, *Westinghouse Research Laboratories.*—The imprisonment of resonance radiation ($\lambda=5890$A and 5896A) in sodium vapor has been measured by methods previously described.[1] For vapor densities less than 10^{14} atoms/cc, for which the line shape is determined by Doppler broadening, the imprisonment time is found to rise monotonically with vapor density. This rise, as well as the absolute magnitude of the time constant, is in agreement with theory.[2] For vapor densities higher than 10^{14} atoms/cc, where dispersion-type pressure broadening prevails, the imprisonment time becomes independent of vapor density. This behavior is also in agreement with theoretical predictions.[2]

[1] Alpert, McCoubrey, and Holstein, Phys. Rev. **76**, 1257 (1949).
[2] T. Holstein, Phys. Rev. **72**, 1212 (1947), and subsequent unpublished calculations.

C6. The Entropy of $MnSO_4\cdot(NH_4)_2SO_4\cdot 6H_2O$ from 0.25°K to 4.2°K in a Magnetic Field. J. W. T. DABBS AND L. D. ROBERTS, *Oak Ridge National Laboratory.*—In connection with the nuclear alignment program here it is necessary to know the entropy of $MnSO_4\cdot(NH_4)_2SO_4\cdot 6H_2O$ in a magnetic field. Assuming no saturation, Casimir[1] gives

$$S/R=(S_0/R)(b/2T^2)+(234T^2/\theta^2)-CH^2/2T^2$$

the symbols having their usual meanings. We have extended, somewhat, previous work on this salt, notably by Benzie and Cook,[2] and Gorter,[3] to find the range of H and T over which this function applies. With $T=(T^*-0.03)$°K, $b=0.033$°K^2, and $\theta=146$°K, per mole of Mn^{++}, we find that the above function describes the behavior of the salt within a few percent from 0.25°K to 4.2°K in the region down to $S=S_0-6.2\times10^7$ ergs/°K. The experiment consisted of the ballistic measurement of T^* and also of the dependence of the adiabatic susceptibility on the applied H for various demagnetization conditions.[1–3] The sample was a sphere compressed from powdered salt.

[1] H. B. G. Casimir, *Magnetism and Very Low Temperatures* (Cambridge University Press, 1940).
[2] R. J. Benzie and A. H. Cooke, Proc. Roy. Soc. (London) **A63**, 213 (1950).
[3] C. J. Gorter, *Paramagnetic Relaxation* (Elsevier Publishing Company, 1947).

C7. A New Record for the Measurement of Absolute Temperature and Entropy at and below 1°K. L. D. ROBERTS AND J. W. T. DABBS, *Oak Ridge National Laboratory.*—The experimental method of the above paper covers only a limited entropy-temperature region. To extend this we use integrals proposed by Casimir: $\Delta S=\int(dM/dT)_H dH$ with temperature constant, and $\Delta T=\int(dM/dS)_H dH$ with entropy constant. Our technique may be used to measure either of the above partial derivatives, but we will discuss $(dM/dS)_H$ only. Two identical secondary coils connected in opposition are placed in the highly uniform field of a large solenoid magnet. In each of these coils a sphere of paramagnetic salt is placed, and their positions are so adjusted that the net quantity of charge generated in the secondary circuit, upon switching off a field H from the large solenoid, will be proportional to the difference of magnetic moment of the two spheres, $\Delta M(H)$. With the help of an auxiliary coil, one isothermally magnetizes the two spheres to slightly different fields and thus to slightly different entropies at 1°K. This known entropy difference, ΔS_0, is essentially constant in an adiabatic demagnetization. Then, $\Delta M(H)$ is measured isentropically as a function of H as indicated above, for *this* ΔS_0. The required partial derivative is then $\Delta M(H)/\Delta S_0$ and the temperature interval $\Delta T(H)$ may be obtained by the graphical integration of this quantity. Experiments are in progress.

THURSDAY MORNING AT 10:00

Shoreham, Terrace Room

(KATHERINE WAY presiding)

Reactions of Transmutation, Hydrogen through Beryllium

D1. The Proton-Proton Reaction and Energy Production in the Sun. EDWARD FRIEMAN, *Polytechnic Institute of Brooklyn*, AND LLOYD MOTZ, *Columbia University*.—Recent revisions of the experimental cross sections for the processes in the carbon cycle[1] have indicated that the proton-proton[2] reaction, $H^1+H^1 \rightarrow H^2+e^+$, can be expected to outweigh by a considerable factor the carbon cycle in the production of energy in stars like the sun. The recent estimates of how big this factor is have been based on the theoretical cross section for the proton-proton reaction calculated for nontensor forces.[3] We have recalculated the cross section for this reaction using tensor forces. The deuteron wave functions employed were those calculated by Feshbach, Schwinger, and Harr,[4] who used central and tensor potentials of the meson type with different ranges. It is shown, using this new cross section, that the proton-proton reaction is even more important as a source of solar energy than had previously been indicated.

[1] R. N. Hall and W. A. Fowler, Phys. Rev. **77**, 197 (1950).
[2] I. Epstein, Ap. J. **112**, 207 (1950).
[3] H. A. Bethe and C. Critchfield, Phys. Rev. **54**, 248 (1938).
[4] Unpublished report.

D2. He_4+T Reactions. E. ALMQVIST, K. W. ALLEN, J. T. DEWAN, AND T. P. PEPPER, *Chalk River Laboratory*.—An unresolved ion beam (20 μamp) of helium (10 percent He^3) is accelerated to 200 kv and used to bombard a target of tritium absorbed in titanium. The following reactions have been observed:

$$He^3+T \rightarrow \alpha+d+14.3^\circ \quad (1)$$
$$\rightarrow He^5+p+11.3 \text{ Mev} \quad (2)$$
$$\rightarrow \alpha+n+p+12.1 \text{ Mev}. \quad (3)$$

The range distribution of the charged particles has been obtained in 200-micron Ilford C2 photographic emulsions covered with 3 mg/cm² Al foil. Measurement of 500 tracks reveals three groups with ranges of approximately 12, 350, and 540 microns and in addition a broad continuum up to 560 microns. The first two groups correspond to the α-particles and deuterons from reaction (1), the third group to the protons from reaction (2), and the continuum to the protons from reaction (3). These assignments were confirmed by energy measurements obtained with a thin KI crystal and 5819 photo-multiplier. Observed at 50° to the ion beam, reactions (1) and (3) are about equal in intensity, while reaction (2) occurs in fewer than 10 percent of the disintegrations. A few 14.7-Mev protons from the He^3+d reaction were observed and were used as an energy calibration point for the scintillation counter.

D3. The Angular Distribution of the Products of the T(d, n)He^4 Reaction. J. L. FOWLER,* J. E. BROLLEY, JR., AND E. J. STOVALL, JR., *Los Alamos Scientific Laboratory*.—Gaseous tritium was bombarded with a focused beam of 10.5-Mev deuterons accelerated by the cyclotron. Charged particles emerged from the reaction volume through plane dural windows. Deuteron-proton scattering provided a method for analysis of the hydrogen impurity. The charged particles passed through two slits which, in conjunction with beam defining slits, fixed the reaction volume. They were counted in a proportional counter. The complete system was contained in a cylindrical vacuum chamber. Alpha-particles were counted from 33° to 94° center-of-mass angle of alpha-particle. Window scattering was investigated by doubling the thickness of dural. No significant difference in cross-section determination was observed. The reaction cross section over this range is estimated to have an absolute error of ±3.5 percent. The range 94° to 180° was studied by neutron counting. Considerably higher pressure of tritium in a different gas cell was used. Detection was done with the radioactivity produced by the $Cu^{63}(n, 2n)Cu^{62}$ reaction, and proton recoil proportional counter telescope. The errors of these measurements are considerably higher. A plot of the angular dependence of the cross section will be presented. From the plot one notices a close similarity[1] to the reaction $He^3(d, p)He^4$ both in magnitude and angular variation.

* Now at Oak Ridge National Laboratory, Oak Ridge, Tennessee.
[1] J. C. Allred, Phys. Rev. **77**, 753 (1950).

D4. Photo-Disintegration of He^4. E. G. FULLER AND M. WIENER, *National Bureau of Standards*.—A study is being made of the photo-disintegration of He^4 using nuclear emulsions in a geometry similar to that used in a previous study of the photo-disintegration of deuterium.[1] Several exposures with different peak energies have been made with the University of Illinois 24-Mev betatrons and the Bureau of Standards 50-Mev betatron in an attempt to sort out the effects of the various competing processes. The neutron background effects were negligible in the 50-Mev betatron exposures. A preliminary analysis has been made of about 1000 tracks. For photon energies up to 23 Mev the results are obscured by corrections for heavy particle recoils and background. These corrections and the comparison of these results with a study made of the inverse reaction,[2] will be discussed. Above 23 Mev the (γ, p) cross section rises to a broad maximum centered at about 27 Mev. The peak cross section is about $7(10)^{-28}$ cm². The angular distribution of the high energy protons in the center-of-mass system is of the form $\sigma(\theta) \sim a+b \sin^2(\theta)$, where $a/b \simeq 2 \pm 1$.

[1] E. G. Fuller, Phys. Rev. **79**, 303 (1950).
[2] Argo, Gittings, Hemmendinger, Jarvis, and Taschek, Phys. Rev. **78**, 691 (1950).

D5. On the $Li^6(n, \alpha)$ Reaction. M. PESHKIN AND A. J. F. SIEGERT, *Northwestern University*.—J. H. Roberts *et al.*[1] have measured the cross section for the $Li^6(n, \alpha)$ reaction close to resonance (250 kev) and found that the angular distribution of the tritons is of the form $A \cos^2\theta + B \cos\theta + C$. The resonance is known to be due to P capture,[2] by which odd compound states of angular momentum 1/2, 3/2, or 5/2 could be formed. The above angular distribution excludes the possibility of pure 1/2. Preliminary measurements at 600 kev[3] show a marked decrease in the ratio A/B, in agreement with the assumption that the angular distribution is determined by P and S capture and $P-S$ interference, the S capture occurring without resonance. A possible connection between this picture and the strong resonance in the total neutron cross section[2] of natural Li and the possibility of deciding whether the compound nucleus has angular momentum 3/2 or 5/2, or whether there is an almost degenerate combination of some pair of 1/2, 3/2, 5/2, or even all three, will be discussed.

[1] Roberts, Darlington, and Haugsnes, Bull. Am. Phys. Soc. **26**, No. 1, abstract C7 (1951).
[2] R. K. Adair, Revs. Modern Phys. **22**, 249 (1950).
[3] J. H. Roberts and H. M. Mann (following abstract).

D6. The Angular Distribution of $Li^6(n, \alpha)H^3$ for 600-kev Neutrons.* J. H. ROBERTS AND H. M. MANN, *Northwestern University*.—The angular distribution for $Li^6(n, \alpha)H^3$ for

270-kev neutrons has been previously reported.[1] The same method is being used to determine the angular distribution for 600-kev neutrons. Li^6-loaded C2 100μ emulsions wrapped in Cd were exposed by J. Morris Blair to $Li^7(p, n)Be^7$ neutrons from the Argonne electrostatic generator. The angle between the direction of neutron incidence and the triton track is measured for all tracks meeting geometrical selection criteria. About 2000 tracks have been measured and divided into 15° intervals in the center-of-mass system. Corrections are made for the background of epithermal neutrons and neutrons at the 250-kev resonance energy. The distribution is highly asymmetric, even more than at 270 kev. The triton yield is highest in the forward direction, has a minimum around 110°, and rises some in the backward direction. The ratio of the forward triton intensity to the backward appears to be around 3:1. Theoretical calculations are reported in an accompanying abstract.[2]

* Supported by the AEC.
[1] Roberts, Darlington, and Haugsnes, Bull. Am. Phys. Soc. **26**, No. 1, abstract C7 (1951).
[2] M. Peshkin and A. J. F. Siegert (preceding abstract).

D7. Electrostatic Analysis of Lithium Reactions.* D. S. CRAIG, C. P. BROWNE, D. J. DONAHUE, R. M. WILLIAMSON, AND R. E. BENENSON, *University of Wisconsin.*—Kinetic energies of product particles of the following reactions have been measured with a spherical electrostatic analyzer[1] using an energy resolution of 500. Bombarding particle energies were determined by a cylindrical electrostatic analyzer calibrated against the $Li^7(p, n)Be^7$ threshold. The angle of observation (134°32′) of the product particles was determined by direct measurement and by scattering protons from a deuterium target. The following are preliminary Q values. Estimates of uncertainties will be given.

Reaction	Q (Mev)
$Li^6(p, He^3)\alpha$	4.027
$Li^7(d, p)Li^8$	−0.181
$Li^7(p, p')Li^{7*}$	−0.4788
$Li^7(d, d')Li^{7*}$	−0.4773.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
[1] Craig, Browne, and Williamson, Phys. Rev. **81**, 304 (1951).

D8. Beryllium and Tritium Reaction Energies.* R. M. WILLIAMSON, C. P. BROWNE, D. J. DONAHUE, D. S. CRAIG, AND K. W. JONES, *University of Wisconsin.*—Using equipment referred to in the preceding abstract, the following preliminary Q values have been obtained:

Reaction	Q (Mev)
$Be^9(p, p')Be^{9*}$	−2.43
$Be^9(p, d)Be^8$	+0.5581
$Be^9(p, \alpha)Li^6$	2.123
$Be^9(p, Li^6)He^4$	2.136
$Be^9(p, \alpha')Li^{6*}$	−0.06
$Be^9(d, Li^7)He^4$	7.175
$T(d, \alpha)n$	17.75.

Final values and estimated errors, along with data on target contamination and magnetic field effects, will be given. The level at 2.18 Mev (corresponding to $Q = -0.06$ Mev) reported in Li^6 was observed at three different bombarding energies and is believed to be the level at ~2.3 Mev previously reported[1] from $Li^7(d, t)Li^{6*}$ reaction. The target of tritium in thick zirconium showed a rapid decrease of tritium density near the surface. It is therefore only possible at present to put a lower limit on this Q.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
[1] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 304 (1950).

D9. Interpretation of (d, n) Angular Distributions.* W. HECKROTTE AND L. SCHECTER, *University of California, Berkeley.*—Recently, determinations[1] have been made of the spatial distributions of neutrons which result from bombardment of various targets by 20-Mev deuterons from the 60-inch cyclotron at Berkeley. In some cases the distributions show small-angle structure which can be interpreted by the mechanism recently proposed by S. T. Butler. This structure is determined by the spins and parities of the nuclear states involved. The experimental method does not allow an identification of the states of the final nucleus, and the observed distributions result from a superposition of the contributions from the various final states. But in the cases of Be^9, Al^{27}, and Cu^{63}, it is possible to show that probably only one of the final states enters in determining the angular distribution. For the $Be^9(d, n)B^{10}$ reaction, production of the ground state of B^{10} only was assumed, and the theoretical and experimental agreement is good enough to assign parity and possible spin values of Be^9. For the $Al^{27}(d, n)Si^{28}$ reaction, similar considerations show that production of the ground state of Si^{28} is unlikely, and the parity and the possible spin values of the resulting excited state have been determined. Similar information is also possible from the $Cu^{63}(d, n)Zn^{64}$ reaction.

* This work was performed under the auspices of the AEC.
[1] L. Schecter, Phys. Rev. **81**, 652A (1951).

D10. Scintillation Spectrometer Measurements of Gamma-Rays from Proton Bombardment of Be^9 and C^{12}. R. L. WALKER AND R. B. DAY, *California Institute of Technology.**—Preliminary measurements of the energies of gamma-rays emitted in a few nuclear reactions have been made with the scintillation counter technique now in common use. A selected 5819 photomultiplier was used in conjunction with a NaI(Tl) crystal 1½ inches in diameter and 1½ inches long. The equipment was checked by using gamma-rays of known energies between 0.5 and 7.4 Mev. The strong gamma-radiation from the 2.56-Mev proton resonance[1] of Be^9 has an energy 3.55 ± 0.07 Mev. This gamma-ray probably emitted by the residual nucleus Li^{6*} left after alpha-particle emission in the $Be^9(p, \alpha)Li^{6*}$ reaction.[1] Further investigation of the origin of this gamma-ray is planned, since a 3.6-Mev level in Li^6 is of special interest as the analog of the ground state in the isobaric nucleus, He^6. The 554-kev proton resonance in C^{13} produces prominent gamma-radiation near 8 Mev and 2.3 Mev, and much weaker radiation near 4 Mev. At this proton energy, no appreciable radiation between 5 and 6 Mev was observed, in contrast to previous reports.

* Supported by the ONR and AEC.
[1] W. J. Hushley, Phys. Rev. **67**, 34 (1945).

D11. Gamma-Rays from Deuteron Bombardment and Slow Neutron Capture. W. E. MEYERHOF, H. RODERICK, AND L. G. MANN, *Stanford University.*—In order to calibrate a NaI(Tl) scintillation detector for slow neutron capture gamma-ray studies we have bombarded Be and C with 2.7-Mev deuterons. In the case of Be, gamma-rays of 6.7 and 6.0 Mev the latter probably originating from the 6.76-Mev level of B^{10}, have been found in addition to other known gamma-rays. In the case of C, gamma-rays of energy 6.1, 4.3, 3.8, and 3.1 (known) Mev have been observed. The 6.1γ is as yet unassigned. The 4.3γ is perhaps due to excitation of the 4.4-Mev level of C^{12} by inelastically scattered $C^{13}(d, p)$ protons. The 3.8 and 3.1γ originate from known levels of C^{13}. Using the above data for calibration we have started the study of slow neutron capture gamma-rays from Cu, Fe, Pb, and other elements. Cu, Fe, and Pb show the prominent ground-state transitions reported by Kinsey *et al.*[1] Fe shows in addition a prominent gamma-ray of 5.9 Mev, probably due to Fe^{56}. A 1.7-Mev gamma-ray needed to complete the cascade to the ground state of Fe^{57} has not yet been found.

[1] Kinsey, Bartholomew, and Walker, Phys. Rev. **78**, 481 (1950).

D12. Energy Release in the Disintegration of Be^8. R. R. CARLSON, *University of Chicago.*—A beryllium target of less than one-kev thickness was bombarded with protons accel-

erated to 372 kev by a Cockcroft-Walton generator. The scattered protons and the products of the reactions $Be^9(p, d)Be^8$ $Be^9(p, \alpha)Li^6$, which are known to occur, were observed at 90° to the beam with a cylindrical electrostatic analyzer. The thin beryllium targets were prepared by evaporation onto nickel foils of average thickness about 100A. This made possible the observation of particles whose energies were less than that of the scattered protons. Preliminary measurements indicate a continuous distribution of particles exists with its upper edge corresponding to doubly charged particles of energy 223 kev. This is attributed to the alpha-particles from the breakup of Be^8. Since carbon accumulation on the target can give an apparently low value for the edge of this distribution, measurements were made on fresh targets only and the position of the Li^6 peak measured at the beginning and end of every run. These peaks gave a Q value of 2.12 Mev for the reaction $Be^9(p, \alpha)Li^6$ in agreement with the accepted value. Using the known Q value for the reaction $Be^9(p, d)Be^8$, the above result gives the energy release in the Be^8 break-up as 72±5 kev. This is to be compared with the value 89±5 kev previously measured.[1]

[1] Tollestrup, Fowler, and Lauritsen, Phys. Rev. 76, 428 (1949).

THURSDAY MORNING AT 9:30

NBS, East Building

(L. A. WOOD presiding)

Symposium of the Division of High-Polymer Physics
Transitions in Polymers

E1. Factors Influencing Glass Formation and Crystallization in Polymers. T. G. FOX, JR., *Rohm and Haas Company.* (30 min.)

Contributed Papers

E2. X-Ray Scattering from Polystyrene as a Function of Temperature. S. KRIMM AND A. V. TOBOLSKY, *Princeton University.*—The x-ray diffraction pattern of unoriented polystyrene has been investigated as a function of temperature with a Geiger counter spectrometer. It has been found that the relative peak intensities of the two halos in the pattern depends on the temperature. The ratio of the intensity of the outer to that of the inner halo is essentially constant between room temperature and about 90°C, at which temperature it falls linearly to a lower value which is then constant above about 160°C. The Bragg spacings corresponding to the peaks of these halos are practically constant up to 160°C above this temperature the spacings increase. An interpretation of these changes in the x-ray scattering pattern is aided by a study of the pattern of oriented polystyrene, it having been possible to obtain x-ray evidence of orientation. These data suggest that the main mechanism of expansion of the material differs in the various temperature regions as a result of structural changes taking place with change in temperature. Specific volume-temperature data tend to support this view. Possible bearing of this information on the second-order transition in amorphous polymers is discussed.

E3. Pressure—Volume Relationships of Rubber and Other Polymers. C. E. WEIR, *National Bureau of Standards.*—The effect of pressure on the volume of raw rubbers and other polymers was studied at room temperature in the pressure range 1000–10,000 atmos. Measurements were made by the piston displacement method. The total decrease in volume ($\Delta V/Vo$) of rubber specimens was approximately 15 percent at 10,000 atmos., which is about twice the volume change expected to occur between room temperature and the second-order transition temperature. No transitions were observed in the rubbers studied, all pressure-volume curves being smooth. All volume changes of polymeric materials studied are of the same order of magnitude.

E4. Studies in Plasticization of Polyvinyl Chloride. III. The Plasticized State: A Special Application of Solubility Principles. M. L. DANNIS, *B. F. Goodrich Company Research Center.*—The behavior of plasticized polyvinyl chloride is considered to be that of a two-component, two-phase system. The dielectric loss factor peak at a fixed frequency defines a transition temperature analogous to the freezing temperature in low molecular weight systems. Transition temperature depressions with added plasticizer follow Flory's crystallization point lowering theory for some PVC-plasticizer systems, but deviate for others. From solution theory analogy, the cohesive energy density of PVC is estimated at 93 cal/cc and the behavior segment as 9 polymerized vinyl groups.

E5. Length-Temperature Behavior of Rubbers.* M. J. FORSTER AND R. L. ANTHONY, *University of Notre Dame.*—As a supplement to stress-temperature and volume dilatometric methods of investigating the second-order transition in rubbers, studies of length-temperature behavior were undertaken. Samples of several rubbers were stretched at 40°C to various initial extensions, under constant loads. They were permitted to creep at that temperature until the time rate of change of length became negligibly small. The temperature was then lowered in steps down through the transition region, and the length-temperature behavior was studied. A wide variety of L *vs* T curves was observed, the shape of the curve obtained in each case depending strongly upon the initial extension and whether this extension was above or below the thermoelastic inversion value. For the rubbers studied, the second-order transition temperature (or region) appears to increase rapidly with increasing initial extension for extensions below the thermo-elastic inversion value, and then to decrease with further increase in initial extension.

* Supported in part by the ONR.

E6. The Determination of the Degree of Crystallinity in Natural Rubber by Dilatometric Methods. RICHARD N. WORK, *National Bureau of Standards.*—The expansivity of amorphous and partially crystalline natural rubber has been determined at temperatures below the glass-transition temperature, T_g, by means of an automatic photoelectric recording interferom-

eter, and above T_g, by means of volume dilatometers in addition to the interferometer. The degree of crystallinity was calculated from the change in expansivity on crystallization above the transition and the expansivity below the transition by a method based on a suggestion of Parks.[1] The expansivity below the transition was found to be independent of the extent of crystallization. Results are expressed in terms of the volume fraction of crystallized rubber for each percent volume decrease upon crystallization, where the actual volume change is reduced to a value at 25°C. Preliminary results give about 10 percent crystallinity for each percent volume decrease. This result is in accordance with x-ray measurements of Goppel and Arlman.[2]

[1] G. S. Parks, J. Chem. Phys. 4, 459 (1936).
[2] J. M. Goppel and J. J. Arlman, Appl. Sci. Research A1, 347–52 and 462–74 (1948).

General High-Polymer Physics

E7. Dielectric Constant of Rubber-Carbon Black Mixtures. CLINTON M. DOEDE, *Connecticut Hard Rubber Company.*—A study has been made of the effect of the carbon black concentration, carbon black particle size, and frequency of the applied voltage upon the dielectric constant of vulcanized and unvulcanized rubber-carbon black mixtures. The dielectric constant has been shown to increase with carbon black concentration, decrease with the frequency of the applied voltage, and for a given black concentration and frequency, to increase very rapidly with decrease in particle radius when the particle radius is of the order of one-tenth micron or less. These observations have been explained with the assumption that the interparticle distances must be sufficiently small to allow interaction of the fields of activity surrounding adjacent particles. This interpretation is in agreement with the observations of Freundlich and of Kallman and Wilstätter.

E8. Theory of Reinforcement in Hydrocarbon and Silicone Rubbers. HENRY A. FAIRBANK, CHARLES A. WALKER, AND CLINTON M. DOEDE, *Connecticut Hard Rubber Company.*—Comparison of extensive data on the effect of pigments on the tensile strength of silicone rubber with similar data on natural rubber and GR-S indicates that the mechanism of reinforcement in three types may be considerably different. In particular, it is noted that the increase in tensile strength at break owing to reinforcing pigments is relatively small (less than 25 percent) in the case of natural rubber but several-fold in the case of GR-S and silicone rubber. Current theories of rubber reinforcement do not adequately account for the differences noted for these types of rubber. It is suggested that the tensile strength at break of unreinforced rubbers (high for natural rubbers and low for GR-S and silicone rubbers) is determined not alone by the strength of the rubber-rubber bonds but by the presence of local imperfections or tear centers. Thus a very important function of the pigment in GR-S and silicone rubber may be the localization of tears. A similar theory is current in studies of strength of metals.

THURSDAY AFTERNOON AT 2:15

NBS, East Building

(A. V. TOBOLSKY presiding)

Symposium of the Division of High-Polymer Physics

The Relative Effects of Frequency and Temperature on Dynamic Mechanical Properties

EA1. Introduction to the Symposium. A. V. TOBOLSKY, *Polytechnic Institute of Brooklyn.* (30 min.)
EA2. The Use of Reduced Variables to Describe Temperature and Frequency Dependence of Dynamic Mechanical Properties. J. D. FERRY, *University of Wisconsin.* (30 min.)
EA3. Dynamic Studies on Polysobutylene. T. W. DE WITT, *Mellon Institute of Industrial Research.* (20 min.)
EA4. Temperature and Frequency Effects on Dynamic Properties: Results of the Cooperative Programme. R. S. MARVIN, *National Bureau of Standards.* (20 min.)
EA5. Temperature and Frequency Effects in the Dynamic Behavior of Swollen and Unswollen Rubber. A. W. NOLLE, *University of Texas.* (30 min.)
EA6. Summary and Discussion. H. S. SACK, *Cornell University.* (30 min.)

THURSDAY AFTERNOON AT 2:15

Shoreham, Main Ballroom

(R. E. MARSHAK presiding)

Production and Capture of Mesons and Electron Pairs

F1. Energy Spectra of π-Mesons Produced at 90° from a 385 Mev Proton Beam.* M. M. BLOCK, S. PASSMAN, AND W. W. HAVENS, JR., *Columbia University.*—Charged π-meson energy spectra from thin targets bombarded by the internal 385-Mev proton beam of the Nevis Cyclotron are being measured. Ilford C-2 nuclear emulsions are imbedded in tapered copper and aluminum absorbers, placed inside the cyclotron vacuum chamber, 2½" below the target, and shielded so as to

receive mesons emitted only at $(90\pm10)°$ from the beam direction. The energy interval from 0 to 125 Mev is included in a single plate. Only those mesons ending in the emulsion and undergoing decay or forming stars are included in the spectra. Using a 0.3 g/cm² carbon target, a π^+ energy spectrum based on 425 π-μ-events has been obtained. When corrected for nuclear absorption,[1] the spectrum exhibits a peak at about 60 to 70 Mev, with half-maxima at about 30 and 90 Mev. This spectrum will be discussed relative to theoretical predictions for meson production. Spectra of other materials are being investigated.

* This work was assisted by the joint program of the ONR and AEC.
[1] Bernardini, Booth, Lederman, and Tinlot, Phys. Rev. **80**, 924 (1950).

F2. Production of Neutral Mesons by γ-Rays Incident on Hydrogen.* A. Silverman and M. Stearns, *Cornell University.*—The reaction $h\nu+H'\rightarrow\pi^0+H'$ is being investigated by bombarding a thin polyethylene target with γ-rays from the 305-Mev Cornell Synchrotron. The reaction is observed by detecting coincidences between the recoil proton and one of the decay γ-rays from the π^0 meson. By measuring the energy and angle of the recoil proton, the energy of the incident γ-ray and the π^0 energy and angle are determined. The proton energy is measured by its pulse height in a NaI crystal in which it expends all its energy. The carbon background was determined for each energy interval and constituted about 40 percent in the lowest energy interval and about 10 percent in the highest. The protons were observed at $30°\pm3°$ corresponding to mesons at about 90° for incident γ-ray energies between 200–300 Mev. Preliminary results yield a differential cross section $(d\sigma/d\Omega)90°=2\times10^{-30}$ cm² per steradian per Q. The cross section as a function of energy is as follows:

E(Mev)	215	240	265	290
$\frac{(d\sigma/d\Omega)90°}{10^{-30}}$	2.4±0.7	2.7±0.7	4.7±0.7	9.1±0.9

Further work is in progress.

* Supported by ONR.

F3. Production of Photo-Mesons from Deuterium and Other Light Elements.* R. M. Littauer and D. Walker, *Cornell University.*—Targets of light elements were bombarded by gamma rays from the 300-Mev electron synchrotron. Charged mesons emitted at 135°, with energies of about 50 Mev, were focused magnetically onto an array of counters. Cloud-chamber[1] and absorption studiess howed negligible contamination of the meson beam by electrons. Relative counting rates for π^- and π^+ mesons were measured for each target. Results are summarized below (errors are statistical; yields normalized to $D=1.00$):

Nucleus	π^-/π^+ Ratio	π^+ Yield/Proton	π^- Yield/Neutron
H		1.20±0.16	0.01±0.12 (per proton)
D	1.39±0.24	1.00±0.14	1.00±0.12
Be	2.25±0.11		
C	1.04±0.05	0.70±0.02	0.50±0.02
O	0.97±0.11	0.58±0.04	0.40±0.03
S	0.78±0.05	0.54±0.02	0.30±0.02

Inequality of the meson life-times would modify the observed π^-/π^+ ratios.

* This work was performed under contract with the ONR.
[1] M. Camac *et al.*, Bull. Am. Phys. Soc. **26**, No. 1, 48 (1951).

F4. Studies on the Production of Neutral Mesons by Protons.* B. J. Moyer, R. Madey, R. H. Hildebrand, N. Knable, and R. Hales, *University of California, Berkeley.*—Experiments are in progress in the deflected 340-Mev proton beam of the 184" cyclotron. Measurements of the yield of neutral mesons *vs* target Z will be reported. For the special case of $p-p$ collisions the yield is observed to be zero ±2 percent of the yield from p-carbon nucleus collisions. The range of error should be reduced by experiments now in progress. Previous efforts at measuring π^0 production from $p-H^2$ collisions employing internal targets and a pair counter have suggested a yield of the order of 10 percent of that from p-oxygen nucleus collisions, but probable errors were at least 50 percent of the effect. In measurements of π^0 production in H^1 and H^2, the yield is so low as to preclude coincidence detection of decay photons. Single high energy photons are detected by counters recording each electron of a pair produced in a $\frac{1}{16}$" Pb converter and separated by scattering. Data are being obtained on the correlation angle distribution for the coincident photons from π^0 decay, which will yield the π^0 momentum distribution. Early results show a maximum yield at a correlation angle near 90° when the counters-target plane is normal to the beam.

* This work was performed under the auspices of the AEC.

F5. Production Ratio of Photo-Mesons from Beryllium.* Henrich A. Medicus, *University of California, Berkeley.*—The method which was used for the determination of the ratio of negative to positive π-mesons produced from photons on carbon[1] has been applied to beryllium. The collimated x-ray beam of the synchrotron (electron energy 322 Mev) strikes the beryllium target. The mesons emerge from the target at an angle of 90° to the beam direction and are detected in 200-μ Ilford C2-emulsions after traversing appropriate absorbers. The ratio, π^-/π^+, is determined from the observed numbers of σ-mesons and π-μ-decays. The preliminary ratio is 2.0 ± 0.3 for the energy range 40–70 Mev. This is considerably higher than the value of 1.3 for carbon. This effect can be explained from the higher neutron-proton ratio in the beryllium nucleus and from the fact that the loosely bound neutron participates relatively strongly in the meson production.

* This work was supported by the AEC and the Schweigerische Arbeitsgemeinschaft für Stipendien in Mathematik und Physik.
[1] Peterson, Gilbert, and White, Phys. Rev. (to be published). McMillan, Peterson, and White, Science **110**, 579 (1949).

F6. μ^- Meson Capture Studies Using Large Liquid Scintillators: I. Apparatus.* F. B. Harrison and J. Warren Keuffel, *Princeton University.*—Two large-area scintillation counters are now being used to study processes related to the capture of μ^- mesons in heavy elements. Each counter consists of a copper tank 1"×12"×12", filled with terphenyl in toluene. Four 1P21 photomultipliers are used. The efficiency for minimum ionizing particles and the relative time lags between the two scintillator tanks have been measured using a beam of fast mesons selected by an auxilliary counter telescope. With a discriminator setting such that 300 noise pulses are counted per sec, the efficiency averaged over the entire tank surface is about 80 percent. The relative lag distribution between the two tanks is approximately gaussian, with a mean deviation of 3 mμ sec. Pairs of photomultipliers are connected in parallel, then mixed by means of cathode followers, amplified with a gain of 200 and a rise-time of about 10 mμ sec, clipped, and fed to a chronotron timing circuit. Echo pulses, probably caused by phosphorescence, are observed to follow the main pulse in a given tank, with a continuous distribution of delays whose average value is around one μsec.

* Supported by the joint program of the AEC and ONR.

F7. μ^- Meson Capture Studies Using Large Liquid Scintillators: II. Results.* J. Warren Keuffel and F. B. Harrison, *Princeton University.*—Evidence has been obtained for the existence of delayed non-ionizing radiations, presumably low-energy gamma-rays or neutrons, associated with the nuclear capture of μ^- mesons in Cu and Sb. Preliminary values for the mean lifetime of the μ-meson in these elements are: Cu, Cu, 120 ± 50 mμ sec.: Sb, 53 ± 20 mμ sec. The errors quoted are

statistical; the instrumental errors will permit a much better precision. We have employed the following disposition: G-M tray A, 7.5 cm of Pb, scintillator tank S_1, 40 g/cm² of Cu or Sb, anticoincidence G-M counters X, scintillator tank S_2, additional anticoincidence counters X. The relative lag between the pulses in S_1 and S_2 is photographically recorded for events (AS_1S_2-X). The background owing to bremsstrahlung of decay electrons has been taken into account. The results support the Wheeler picture of the meson capture process[1] and should lead to an improved value for the coupling constant between μ-mesons and nuclei.

* Supported by the joint program of the AEC and the ONR.
[1] J. A. Wheeler, Revs. Modern Phys. 21, 133 (1949).

F8. Decay and Capture of Mesons in Photographic Emulsions.* W. F. FRY, *Iowa State College*.—Meson events have been studied in Eastman NTB-3 plates which were exposed to cosmic radiation in the stratosphere. A total of 41 π-μ-decays, 118 negative π-stars, and 500 mesons which stopped in the emulsion without associated particles other than electrons, were studied. It is estimated that 68 ± 7 percent of the μ-mesons decayed in the emulsion. One or more low energy electrons in the interval from 15 to 70 kev were observed from 58 of the mesons which stopped in the emulsion without associated particles other than electrons. In 10 cases, two such electrons were observed from the same meson. In 2 cases, three electrons were observed. The energy distribution of these electrons can be represented by $N(E)\sim\exp(-E/E_0)$. One or more low energy electrons were observed from 22-meson stars. No electrons of energy gretter than 0.2 Mev were observed from the meson stars. The energy distribution and the percentage of low energy electrons from meson stars and from μ-mesons are the same, within statistical limits. These facts indicate that the low energy electrons tre due to the interaction of the negative mesons with the electronic shells of the heavy atoms in the emulsion.

* Supported in part by grants from the Research Corporation and the Iowa State College Research Foundation.

F9, Nuclear Interactions of μ-Mesons Underground. S. HAYAKAWA, *Cornell University*.—The nuclear interactions of μ-mesons detected in two underground experiments, (a) by George and Evans with photographic plates, and (b) by Cocconi and Cocconi-Tongiorgi with neutron counters, are analyzed. Both experiments can be explained by the interaction with matter of the electromagnetic field of the μ-mesons. Most of the nuclear disintegrations underground are produced either directly by the μ-mesons or by the N-component in equilibrium with them. An interpretation is given of the neutron showers of experiment (b) using the following pictures: (1) a μ-meson is scattered by a nucleon in a Pb nucleus, and its recoil nucleon starts a nucleon cascade; (2) a nucleon produced above the apparatus enters the Pb absorber and keeps on developing the nucleon cascade inside it. In both cases each step of the development of the nucleon cascade leads to the production of neutrons of moderate energies (1–10 Mev). The multiplicity spectra of the neutron showers thus generated are calculated. Both the shapes and the average multiplicities are in fair agreement with the experimental data. Other questions concerning the interaction of μ-mesons are discussed.

F10. A Search for Nuclear Disintegrations Associated with the Stopping of μ-Mesons in Argon Gas.* G. W. MCCLURE, *Bartol Research Foundation*.**—A high pressure ionization chamber operating in conjunction with an anticoincidence counter controlling arrangement to detect the entrance of slow penetrating particles has been used to set an upper limit on the frequency of star production by μ-mesons captured in argon. To determine the background rate of ion chamber events not associated with meson capture, the chamber was operated part of the time with an equivalent filling of nitrogen—a gas having a low μ^- capture probability. All of the larger ionization pulses which occurred in either gas could be attributed either to slow mesons (85 percent) or protons (15 percent) which stopped in the chamber without producing nuclear events in the gas. Comparison of the argon and nitrogen pulse height distributions indicates that, if any, less than 18 percent of the negative μ-mesons stopped in argon produce stars in which the ejected charged nucleons have a combined energy greater than 5 Mev.

* Assisted in part by the ONR and AEC.
** Experimental work performed at the University of Chicago.

F11. Pair Production by Electrons. MORTON CAMAC, *Cornell University*.—An experiment was started to observe pair production by electrons in the nuclear field by measuring the positrons emitted from a target irradiated directly by the synchrotron electron beam. Positrons produced in the target are bent out of the donut through a thin aluminum port by the magnetic field. These are detected in a counter telescope consisting of a thin-walled proportional counter, two inches of aluminum, and a NaI crystal detector with approximately a 15-Mev bias. For a coincidence in the two counters an ionizing particle must have at least 40-Mev energy. The positrons can be produced either directly by the electrons or through a double process in which bremsstrahlung is first produced and then converted into pairs in the same target. Using the bremsstrahlung beam as a monitor the direct process is independent of the target thickness, while the double process varies linearly. Thus, we get a direct comparison of the two effects. Preliminary data give a ratio of the cross section of the direct to the double effect of from 0 to 0.003 for the case of the positron having about 90 percent of the initial electron energy of about 250 Mev.

F12. Energy Sharing of Electron Pairs at 17 Mev. B. DAYTON, *Cornell University*.*—The energy sharing between positrons and electrons near the ends of the relative energy spectrum has been measured in Al, Cu, Sn, and Pb. The pairs were produced by the 17-Mev lithium gamma-rays. The experiment, employing coincidence counting, was designed to disclose any sizable asymmetry between positron and electron energies, such as might be expected for pair production in heavy elements. These measurements, together with an absolute calibration of the gamma-ray yield from the cyclotron,[1] also provide absolute differential cross sections for pair production and Compton scattering. Applying the Bethe-Heitler and Klein-Nishina formulas to the known spectrum[2] of the lithium gamma-rays, differential cross-section curves have been prepared to compare to the experimental distributions. Qualitatively, the experimental cross sections are in good agreement with theory, though they are low by 10–15 percent for Sn and Pb, both for pair production and Compton scattering. The asymmetry found is possibly significant for Pb and Sn, but it is certainly masked by the statistical errors for Cu and Al.

* Now at the Massachusetts Institute of Technology.
[1] McDaniel, Walker, and Stearns, Phys. Rev. 80, 807 (1950).
[2] R. L. Walker and B. D. McDaniel, Phys. Rev. 74, 315 (1948).

F13. Evidence for Formation of Positronium in Gases.* MARTIN DEUTSCH, *Massachusetts Institute of Technology*.—We find that in some gases a considerable fraction of positrons is annihilated much more rapidly than can be explained on the assumption that they are moving freely through the gas. This indicates their attachment to bound structures where the electron density is high. There is strong evidence that in N_2, for example, this structure is a free positronium atom. Many of these atoms survive for about 10^{-7} sec in the ^3S state in which two-quantum annihilation is forbidden. Evidence for the continuous gamma-ray spectrum owing to

the three-quantum annihilation has been found with a scintillation spectrometer. Addition of 5 percent of NO to N_2 reduces the number of delayed annihilations by a factor of 3 and removes the continuous gamma-spectrum. This is interpreted as conversion of the ^3S to the ^1S state, which decays in 10^{-10} sec. This conversion can occur in NO by electron exchange. O_2, in which conversion can occur only for atoms with more than 1.6 ev kinetic energy, behaves intermediate between N_2 and N_2+NO.

* Supported in part by the joint program of the AEC and ONR.

THURSDAY AFTERNOON AT 2:30

Shoreham, West Ballroom

(R. M. BOZORTH presiding)

Ferromagnetic Substances

G1. Motion of a Domain Wall in Fe_3O_4. J. K. GALT. *Bell Telephone Laboratories.*—A diamond-shaped ring of Fe_3O_4, with each leg along a direction of easy magnetization, is cut from a synthetic single crystal[1] of Fe_3O_4 with its face in a 110 plane. This sample is expected to have a simple domain pattern analogous to that observed in silicon iron by Williams and Shockley.[2] The hysteresis loop has the expected square shape, with a coercive force of 0.25 oersted. Pictures of the domain pattern will be shown. Initial permeability *vs* frequency follows a relaxation curve with $\mu=5000$ at $\nu=0$ and a relaxation frequency of approximately 2000 cycles. Wall velocity in cm/sec is about 10^3 times the applied field in oersteds. The relaxation time computed from these measurements will be compared with that deduced from the width of the ferromagnetic resonance line.

[1] The crystal used was made available by Professor A. von Hippel (Laboratory for Insulation Research, M.I.T.). This crystal growth work was sponsored on contract jointly by the ONR, the Army Signal Corps, and the Air Force.
[2] H. J. Williams and W. Shockley, Phys. Rev. 75, 178 (1949).

G2. Old Data on Hall Effect in Nickel. EMERSON M. PUGH, N. ROSTOKER, AND A. I. SCHINDLER, *Carnegie Institute of Technology.*—Old Hall effect data on ferromagnetics are generally consistent with the relation $E_H=R_0(H+\alpha 4\pi M)ib$. Extensive data by A. W. Smith[1] on pure nickel taken over wide ranges of magnetic field H and temperature θ is shown to be consistent with an R independent of H and θ and an α independent of H but increasing rapidly with θ. For this analysis, data from Weiss and Forrer[2] giving M *vs* H for nickel over the same ranges of H and θ, were needed. The relationship appears to hold above and below the Curie point temperature and above and below the magnetic fields required for saturation.

[1] A. W. Smith, Phys. Rev. 30, 1 (1910).
[2] P. Weiss and R. Forrer, Ann. Physik 5, 153 (1926).

G3. Hall Effect in Copper-Nickel Alloys. A. I. SCHINDLER AND EMERSON M. PUGH, *Carnegie Institute of Technology.*—The Hall constant R_0 and the field parameter α defined by $E_H=R_0(H+\alpha 4\pi M)ib$ have been experimentally determined for various alloys of copper and nickel. A brief description of the apparatus and a summary of the results will be given. The Hall constant R_0 increases with copper content until a maximum is reached at about 30–40 percent copper. It then decreases with increasing copper content. The number of conduction electrons as calculated from the Hall constant R_0 is consistent (within a factor of two) with magnetic data and the existing band picture of the alloy system. The field parameter α varies approximately linearly with copper content from 10 for pure nickel to 40 for 30 percent Cu−70 percent Ni at room temperature.

G4. Hall Effect and the Technical Magnetic Force. N. ROSTOKER, *Carnegie Institute of Technology.*—The Bloch-Sommerfeld theory of conductivity has been applied to the calculation of momentum transferred to a crystal lattice by conduction electrons in the presence of a magnetic field for the following cases: (i) pure electronic conduction, (ii) pure hole conduction, (iii) simultaneous electronic and hole conduction. In the first two cases the technical magnetic body force $\mathbf{f}=(\mathbf{J}\times\mathbf{B})/c$ results entirely from the action of the Hall electric field on the crystal lattice. In the third case the body force is partially due to momentum transfer and partially due to the action of the Hall electric field. In the case of nickel, it is entirely due to momentum transfer. The unusual experimental results obtained for the Hall effect in ferromagnetics are discussed in the light of these calculations.

G5. Optical Rotation by Ferromagnetic Substances. CHARLES KITTEL, *Bell Telephone Laboratories.*—The plane of polarization of light experiences a rotation on transmission through ferromagnetic bodies (faraday effect) and also on reflection at the surfaces of ferromagnetic bodies (Kerr effect). The quantum theory of the faraday effect has been discussed by Hulme,[1] employing the formalism of spin-wave theory, and he succeeds in accounting for the order of magnitude of the observed[2] saturation rotation in iron, which is 380,000 degrees per centimeter. We discuss a rather simpler model leading to the faraday rotation and point out the additional substantial changes in the rotation which are caused by the incomplete quenching of the orbital angular momentum of the ground state of the magnetic atoms. The effect of incomplete quenching have recently been discussed by Van Vleck, Polder, and the author in connection with the interpretation of ferromagnetic resonance and gyromagnetic ratio experiments. The effect on the rotation may be as large as the effect considered by Hulme.

[1] H. R. Hulme, Proc. Roy. Soc. (London) **A135**, 237–257 (1932); see also O. Halpern, Ann. Physik [5] 12, 181 (1932).
[2] H. König, Optik 3, 101–119 (1948).

G6. Neutron Diffraction Studies of Antiferromagnetism in Manganous and Nickelous Fluoride. R. A. ERICKSON* AND C. G. SHULL, *Oak Ridge National Laboratory.*—Neutron diffraction studies have been made on MnF_2 and NiF_2 between 20 and 300°K. Both compounds were found to be antiferromagnetic with Curie points between 70 and 80°K. In the region of magnetic saturation the data can be accounted for by a model in which the magnetic moments of the paramagnetic ions are directed along the short axis of the tetragonal system, as indicated by the susceptibility measurements of Griffel and Stout[1] on a single crystal of MnF_2, and the magnetic and chemical unit cells are of the same size. The temperature dependence of the integrated intensity in the magnetic reflections was found to be in agreement with that cal-

culated from the spontaneous magnetization predicted by Van Vleck[3] for a simple antiferromagnetic lattice.

* Graduate Fellow of the Oak Ridge Institute of Nuclear Studies.
[1] M. Griffel and J. M. Stout, J. Chem. Phys. 18, 1455–58 (1950).
[3] J. H. Van Vleck, J. Chem. Phys. 9, 85–90 (1941).

G7. Magnetostrictive Vibration of Prolate Spheroids of Nickel and Nickel-Iron Alloys.* J. S. KOUVELITES, L. W. MCKEEHAN, AND F. J. BECK, *Yale University.*—Small centrally-clamped ferromagnetic specimens have been subjected to an alternating, axial magnetic field and allowed to vibrate longitudinally in the frequency region of their fundamental mode. The static magnetic bias, simultaneously impressed on the specimens, was brought up along the static magnetization curve to a point well above the "knee" and then taken around a complete hysteresis loop. The analysis of the vibrational response yielded values for several magnetic and mechanical parameters: magnetostriction constant, incremental permeability, modulus of elasticity, etc. The variation of these parameters with composition and magnetic bias has been examined qualitatively in the light of present domain theory. While all the specimens were similarly annealed before measurement, the nickel was studied in an untreated state, as well.

* Assisted by the ONR.

G8. Recrystallization of Fe-Co Alloys.* B. SAWYER, R SMOLUCHOWSKI, AND R. W. TURNER, *Carnegie Institute of Technology.*—In connection with the previously reported[1] influence of magnetic field on the recrystallization texture of Fe–Co alloys a systematic study of recrystallization of these alloys is being conducted. The recrystallization texture is a sum of three ideal orientations: (100)·[110], (100)·[$\bar{1}$10]$\sim$15° and (111)·[$\bar{1}$10]$\sim$15°, and the experiment shows that the relative proportion of a given texture is a function of temperature of recrystallization. At temperatures below 700° the apparently predominant texture is (100)[$\bar{1}$10], which is similar to the texture in rolled material before recrystallization. With increasing temperature the other two textures gain in intensity, and in the proximity of 900°C there is no trace of the low temperature texture. This behavior allows to estimate the respective activation energies and correlates with the influence of magnetic field. All measurements in this study are made with help of the continuous pole figure camera.[2] A new positioning of the sample increased by 50 percent the area of the stereographic projection covered in one exposure and the only missing part is that within 45 degrees of the center.

* Research sponsored by a contract with AEC.
[1] R. Smoluchowski and R. W. Turner, J. Appl. Phys. 20, 745 (1949).
[2] R. Smoluchowski and R. W. Turner, Physica 16, 397 (1950).

THURSDAY AFTERNOON AT 2:15

Wardman Park, Continental Room

(WALTER GORDY presiding)

Microwave Spectra and Magnetic Resonance

H1. The Spin of O^{18}. S. L. MILLER,* A. JAVAN, AND C. H. TOWNES, *Columbia University.*†—Observation of the microwave absorption spectrum of $O^{16}O^{18}$ and $O^{18}O^{18}$ in the 5-mm region shows that the spin of O^{18} is zero. In the region between 58,300 mc and 59,900 mc all of the expected $O^{16}O^{18}$ and $O^{18}O^{18}$ lines have been observed and identified. Their positions are predicted closely by Schlapp's formula with appropriate changes in constants for isotopic substitutions. The $K=8$, $J=7\rightarrow8$ transition which should be at about 58,600 mc, the $K=6$, $J=5\rightarrow6$ transition at about 59,375 and the $K=4$, $J=5\rightarrow4$ transition at about 59,400 mc for $O^{18}O^{18}$ are all missing. Other observations on O^{18} had failed to disclose quadrupole hyperfine structure, and the $O^{16}O^{18}$ lines show no evidence of magnetic hyperfine structure, which indicates a zero spin for O^{18}. However, real proof that the spin of O^{18} is zero rests on the method of alternating intensities in the homonuclear molecule $O^{18}O^{18}$. Since alternate rotational levels of $O^{18}O^{18}$ do not exist and it is the same levels which are forbidden in $O^{16}O^{16}$, the spin of O^{18} is zero and the O^{18} nucleus follows Bose-Einstein statistics. Magnetic hyperfine structure found in $O^{16}O^{17}$ indicates an O^{17} spin greater than $\frac{1}{2}$. The authors wish to thank Professor A. O. Nier for a sample of enriched oxygen.

* AEC Predoctoral Fellow.
† Work supported by the AEC.

H2. The Quadrupole Moment of O^{17}. S. GESCHWIND, G. R. GUNTHER-MOHR, AND C. H. TOWNES, *Columbia University.**—Hyperfine structure due to O^{17} in the microwave absorption spectrum of OCS has previously been searched for without success.[1,2] Hyperfine splitting in the $J=1\rightarrow2$ transition of OCS has now been found in a high resolution spectrometer. The O^{17} spin appears to be 5/2, although this has not yet been unambiguously determined because of incomplete resolution of the spectrum. The quadrupole coupling constant, however, can be definitely given as $eqQ=-1.2\pm0.2$ Mc/sec. Estimating q in OCS at the oxygen nucleus as $3.4\pm1.2\times10^{15}$ esu, the quadrupole moment is $Q=-0.005\pm0.002\times10^{-24}$ cm^2. The sign and very small magnitude of this quadrupole moment are in agreement with expectations from the single-particle model. The small magnitude indicates that the odd neutron in O^{17} produces very little distortion of the closed shell of 8 protons and 8 neutrons. The authors are grateful to Professor A. O. Nier for supplying a sample of oxygen enriched in O^{17}.

* Work supported by the AEC.
[1] W. Low and C. H. Townes, Phys. Rev. 75, 529 (1949).
[2] Bianco and Roberts, Thesis, Iowa State University, 1950.

H3. The Hyperfine Structure of the $^3P_1$ Metastable State of the Stable Chlorine Isotopes.* V. JACCARINO AND J. KING, *M.I.T.*—The hfs of the metastable $^3P_1$ state of the Cl^{35} isotope has been observed by the atomic beam resonance method. The $(2, -1\leftrightarrow2, -2)$ low frequency line has been measured in fields up to 350 gauss, using the $(3, -1\leftrightarrow3, -2)$ low frequency line of the $^3P_1$ state of Cl^{35} to calibrate the magnetic field. From this a tentative value of

$$\Delta\nu_1^{35}=2a_1^{35}=2135\pm11 \text{ mc/sec}$$

has been established. The high frequency $\Delta F=\pm1$ lines are now being investigated in the Zeeman region to observe $\Delta\nu$ directly for both isotopes. The results of these experiments should allow a direct comparison of the magnetic hyperfine interaction of the chlorine isotopes, without the complication of the presence of an electric quadrupole interaction as in the $^3P_1$ states. This ratio is of interest since the ratio as measured in the $^3P_1$ states of the chlorine isotopes differs from the ratio

of the magnetic moments as measured by the nuclear resonance method by an amount considerably outside the quoted experimental uncertainties.[1]

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.
[1] W. G. Proctor and F. C. Yu, Phys. Rev. 81, 20 (1951).

H4. *l*-type Doubling Transitions in DCN. YU TING, THOMAS L. WEATHERLY, AND DUDLEY WILLIAMS, *The Ohio State University*.—Absorption lines due to direct transitions between *l*-type doubling levels within a given rotational energy level of a linear molecule were first reported by Shulman and Townes[1] for the molecules OCS and HCN. The present work has revealed the existence of absorption lines due to similar transitions in the DCN molecule. The observed splittings $\Delta\nu$ and the q-values defined by $q=\Delta\nu/J(J+1)$ are given in Table I. The value of q calculated from Nielsen's expression[2]

TABLE I. *l*-type doubling transitions in DCN.

Rotational level	Observed frequency $\Delta\nu$	Observed q-value
11	24,539.2± 0.1 mc/sec	185.903±0.001 mc/sec
12	28,993 ±15 mc/sec	185.89 ±0.15 mc/sec

for *l*-type doubling is 183.6 mc/sec. The observed q-value for DCN is 1.2 percent higher than the calculated value, whereas the observed q-value for HCN is 0.9 percent lower than the calculated value.

[1] R. G. Shulman and C. H. Townes, Phys. Rev. 77, 421 (1950).
[2] H. H. Nielsen, Phys. Rev. 75, 1961 (1949).

H5. Microwave Absorption Spectrum of Formic Acid Vapor.* JOHN D. ROGERS AND DUDLEY WILLIAMS, *The Ohio State University*.—A study of the microwave spectrum of formic acid vapor has revealed absorption lines at the following frequencies: 22,326.42±0.11; 22,471.14±0.04; 23,203.41 ±0.04; 24,568.99±0.03; 27,817.12±0.13; and about 31,200 mc/sec. On the basis of infrared data, Stark patterns, and variation of line intensity with variations in temperature, it has been possible to identify some of the observed lines with certain rotational transitions of monomeric HCOOH. From the frequencies associated with the $J_\tau=0_0\rightarrow1_{-1}$ and $J_\tau=5_{-4}\rightarrow5_{-3}$ transitions, it is possible to obtain values of the rotational constants B and C appropriate to these transitions; the values obtained are $B=0.399901\pm0.000002$ cm^{-1} and $C=0.349696\pm0.000002$ cm^{-1}. Assuming that HCOOH is a planar molecule[1] and that the relation $I_C=I_A+I_B$ *is applicable*, one obtains a value $A=2.7855$ cm^{-1}.

* This work was done in connection with Contract AF 19(122)-13 between the Geophysical Research Laboratories and the Ohio State University Research Foundation.
[1] S. H. Bauer and R. M. Badger, J. Chem. Phys. 5, 852 (1937).

H6. The Low Temperature Infrared Spectrum of Solid Neopentane. R. M. HAINER, M. ELAINE HUNGERMAN, AND GILBERT W. KING, *Arthur D. Little, Inc.*—The infrared spectrum of solid neopentane has been observed at 77° and 4°K. Its infrared active vibrations have threefold degeneracy, removed by the crystalline field. The gas-phase band at 1475 cm^{-1} is resolved into components at 1489, 1474, and 1466. The 1376-cm^{-1} band shows two lines at 1364 and 1361 with indication of a third at 1366. The 1249-cm^{-1} band appears at 1261 with possible components at 1264, 1261, and 1258. The 921-cm^{-1} band appears as a singlet, unchanged in position, with width corresponding to an unresolved triplet with separations less than 1.5 cm^{-1}. On the basis of intensity, the magnitude of splitting, and the shift from gas to solid, the first three bands are probably of the same type, the 921 band being the skeletal frequency. At 77°K the widths of components are determined by their natural widths (cm^{-1}) and not by the instrument. Since neopentane is spherical and the most likely molecule to have quantized molecular rotation, a stringent test for this hypothesis was made by observation at 4°K, where at 1370 cm^{-1} neither narrowing nor improved resolution was obtained although experimental conditions were favorable.

H7. New Microwave Data on Trichlorides of Elements of the Fifth Column.* P. KISLIUK AND C. H. TOWNES, *Columbia University*.—From the width and contour of the unresolved $J=5\rightarrow6$ transition[1] of $AsCl_3$, $(eQ)_{As}$ may be estimated as -173 ± 20 Mc, significantly less than that[2] of AsF_3. The $J=6\rightarrow7$ transition of $SbCl_3$ has been observed at slightly above room temperature (31°–45°). From the $Sb^{121}Cl_3^{35}$ line at 24,554 Mc and the $Sb^{123}Cl_3^{35}$ line at 24,510 Mc, the internuclear distance and bond angle may be given as 2.325±0.005A and 99.5±1.5°. The lines due to $SbCl_2^{35}Cl^{37}$ and $SbCl^{35}Cl_2^{37}$ as well as the $J=7\rightarrow8$ transition of $SbCl_3^{35}$ were also observed. All of the $SbCl_3$ lines were extremely broad due to the unresolved Sb hyperfine structure and higher vibrational states, being roughly 35 Mc wide. The ratio of the Sb quadrupole moments may be estimated from line widths as approximately 1.3, in agreement with recent more precise measurements,[3] but in disagreement with an older value.[4] The quadrupole effects of the chlorine nucleus may be neglected in both of these cases.

* Work supported jointly by the Signal Corps and ONR.
[1] P. Kisliuk and C. H. Townes, J. Chem. Phys. 18, 1109 (1950).
[2] Dailey, Rusinow, Shulman, and Townes, Phys. Rev. 74, 1245 (1948).
[3] C. C. Loomis and M. W. P. Strandberg, M.I.T.R.L.E. Tech. Rpt. No. 167 (1950).
[4] K. Murakawa and S. Suwa, Phys. Rev. 76, 433 (1949).

H8. The Structure and Dipolmoment of Trioxane.* E. AMBLE,† *Columbia University* (Introduced by C. H. TOWNES).—The $J=1\rightarrow2$ transition for trioxane $C_3^{12}H_6O_3^{16}$ and the $J=1\rightarrow2$ transition for $C_3^{13}C^{12}H_6O_3^{16}$ have been observed and measured:

$C_3^{12}H_6O_3^{16}$	$J=1\rightarrow2$		21,094.3 Mc
$C_3^{12}C^{13}H_6O_3^{16}$	$J=1\rightarrow2$	$K=0$	20,900 Mc
	$J=1\rightarrow2$	$K=1$	20,804 Mc.

The molecule is symmetric top, and the structure which gives the best fit to the observed frequencies is a chairform ring with C–O bond distance 1.41A and $\angle C-O-C=\angle O-C-O=109°$. Electron diffraction experiments give 1.40±.02 for the bond distance and 112°±3° for the angles.[1] Further work on isotopic species of this molecule is in progress. The dipolmoment of the molecule has been measured by the first stark shift as 2.08±.01 Debye units. Measured in benzene solution, the moment has been found to be 2.18 Debye.[2]

* Work supported jointly by the Signal Corps and ONR.
† On leave from Oslo University.
[1] P. W. Allen and Sutton, Acta Cryst. Vol. 3, Part I, 46, 72 (January, 1950).
[2] A. A. Maryott and S. F. Acree, J. Research Natl. Bur. Standards 33, 71 (1944).

H9. Optical Detection of Radiofrequency Resonance. Lifetime of the $^3P_1$ State of Hg.* J. BROSSEL, *M.I.T.*—Changes in the degree of polarization of resonance radiation, induced by radiofrequency resonance between Zeeman sublevels,[1] have been studied for the even and 199 isotopes of Hg. The radiofrequency resonance line shape is accurately accounted for by theory.[2] The extrapolated line width for zero rf amplitude leads to a lifetime of 1.55×10^{-7} sec for the even isotopes at 0°C, which is about 30 percent longer than previous estimates. Preliminary measurements for Hg^{199} indicate a value of the lifetime for the $^3P_1$ level within 5 percent of the above value, in contradiction to some recent measurements.[3]

* This work was supported in part by the Signal Corps, Air Materiel Command, and ONR.
[1] A. Kastler and J. Brossel, Compt. rend. 229, 1213 (1949); Brossel, Sagalyn, and Bitter, Phys. Rev. 79, 196–225 (1950).
[2] F. Bitter and J. Brossel, Technical Report No. 176, Research Laboratory of Electronics, M.I.T. (1950).
[3] R. Lennuier and J. L. Cojan, Compt. rend. 231, 1450 (1950).

H10. A Fine Structure in Nuclear Induction Signals from Ethyl Alcohol. M. E. PACKARD AND J. T. ARNOLD, *Stanford University*.[1]—The construction of a nuclear induction ap-

paratus which will resolve lines separated by about 1 milligauss out of 7600 gauss has enabled us to see structure in signals from protons in organic compounds. This resolution is achieved by the use of a shimmed and stabilized electromagnet which has 12-inch pole pieces; and the use of a cylindrical sample 2 mm by 1 cm. The nuclear induction signal is observed on an oscilloscope. Confusing transient effects are reduced by sweeping the magnetic field at a rate of about 10 milligauss per second. Nuclear induction signals from protons in ethyl alcohol show three well-separated lines which correspond to the OH, CH_2, and CH_3 groups. The CH_2 and CH_3 peaks are split into at least four and three lines, respectively, spaced by 1.5±0.5 milligauss. Neither the OH peak in ethyl alcohol nor the OH and CH_3 peaks in methyl alcohol show such splitting. The separation between the OH and CH_2 lines decreases by about a factor of two for a temperature change from −80°C to +70°C, while the spacing between the CH_2 and CH_3 lines is not measurably altered.

[1] Arnold, Dharmatti, and Packard, to be published in the *Journal of Chemical Physics*.

H11. Nuclear Magnetic Resonance Effects in Gases.* FRANK VERBRUGGE AND ROBERT L. HENRY, *Carleton College.*—The saturation method[1] has been used to study nuclear magnetic resonance in gaseous ethane from a pressure of 8 atmospheres through its critical pressure. Within experimental error, the product PH_1 remains constant, where P is the pressure and H_1 is the rf field strength required to reduce the output of the "lock-in" amplifier by a given factor. This result is consistent with the theoretical proportionality[1] to P of T_1 (spin-lattice relaxation time) and T_2 (spin-spin relaxation time), if one assumes that $H_1^2T_1T_2$ determines the degree of saturation. Using the reported values[2,3] of T_1 and T_2 for water and taking $T_1=T_2$ in agreement with theory, the line width for ethane varies from 9×10^{-4} gauss at 8 atmospheres to 4×10^{-3} gauss at 34 atmospheres.

* Work supported by the Research Corporation.
[1] Bloembergen, Purcell, and Pound, Phys. Rev. **73**, 679 (1948).
[2] E. L. Hahn, Phys. Rev. **76**, 145 (1949).
[3] H. A. Thomas, Phys. Rev. **80**, 901 (1950).

THURSDAY AFTERNOON AT 2:30

NBS, Materials Testing

(E. C. CRITTENDEN presiding)

Invited Papers

I1. The Work and Plans of the Physikalisch-Technische Bundesanstalt. A. SCHEIBE, *Physikalisch-Technische Bundesanstalt, Braunschweig.* (40 min.)

I2. Temperature Effects in Electron-Bombardment Conductivity and in Impurity Semiconductors. W. EHRENBERG, *Birkbeck College, London.* (40 min.)

THURSDAY AFTERNOON AT 2:15

Shoreham, Terrace Room

(C. C. LAURITSEN presiding)

Reactions of Transmutation, Boron Onwards; Electron Capture

J1. Cross Section for the $B^{10}(n,\alpha)$ Reaction from 0.35 to 2.6 Mev Neutron Energy.* D. W. MILLER,† BEN PETREE, AND C. H. JOHNSON, *University of Wisconsin.*—The cross section for the $B^{10}(n,\alpha)$ reaction was measured as a function of neutron energy using a cylindrical proportional counter containing BF_3 and argon. Good pulse height resolution was obtained in this counter by the use of guard sleeves around the central wire, which were held at an intermediate voltage to reduce end effects. Disintegration pulses from the counter were recorded photographically. The disintegration cross section was found to lie below the 1/v extrapolation of the thermal cross section except at the peak of a resonance observed at 1.9 Mev, where the cross section coincides with the 1/v extrapolation. This resonance has a width of about 400 kev, a peak value of 0.53 barn, and a total variation of the cross section of 0.35 barn. The ratio of the number of disintegrations leading to the ground state of Li^7 to the number leading to the excited state increases smoothly from 0.2 at 0.35 Mev to a maximum of 2.3 at 1.9 Mev, and decreases again to 0.8 at 2.6 Mev.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
† AEC Predoctoral Fellow.

J2. Neutron Yield and Angular Distribution for $B^{11}(d,n)C^{12}$ and $B^{10}(d,n)C^{11}$. W. H. BURKE AND J. R. RISSER, *The Rice Institute.**—Relative yields of neutrons from thin targets of (1) natural boron and (2) separated B^{10} bombarded by deuterons were measured in the energy range 0.3 to 1.9 Mev. Yield curves were similar when made either with a counter which had approximately equal sensitivity for neutrons of all energies or with a gas recoil counter biased to count only the most energetic groups. Broad low resonances occur in the forward direction at about 0.9 Mev for B^{10} and at about 1.1 and 1.6 Mev for B^{11}. Angular distributions in the range 1.0 to 1.8 Mev show maxima in the forward direction: at 0° for B^{11} and at about 35° for B^{10}.

* Assisted by the ONR and AEC.

J3. Angular Distribution of Gamma-Rays from $B^{11}+H^1 \rightarrow C^{12}+\gamma$. B. D. KERN,* C. D. MOAK, W. M. GOOD, AND G. P. ROBINSON, *Oak Ridge National Laboratory.*—It has been found that the gamma-rays from this reaction consist of a single transition to the ground state[1] accompanied in greater amount by a 12.1-Mev and a 4.6-Mev gamma-ray in cascade. The 12.1 Mev is known to come out first.[2] Besides using these

gamma-rays to study the scintillation spectrometer, the latter is being used to study the angular distribution of these gamma-rays. The angular distribution between the two cascade γ-rays is being studied as well as the angular distributions of the separate γ-rays with the beam. So far it has been found that the 12-Mev radiation has a distribution $w(\vartheta) = \text{const}(1+0.15\cos^2\vartheta)$. The 16.7-Mev radiation is isotropic to within the present error of measurements which, due to the small yield, is still greater than 10 percent.

* Now at University of Kentucky.
[1] R. L. Walker, Phys. Rev. **79**, 172 (1950).
[2] R. L. Walker (private communication).

J4. Q Values of the $C^{13}(d, p)C^{13}$, $Be^{9}(d, p)Be^{10}$, and $O^{16}(d, p)O^{17}$ Reactions. ERNEST D. KLEMA AND G. C. PHILLIPS, *The Rice Institute.*—An annular magnet similar to the one used at M.I.T. by W. W. Buechner[1] and his associates has been constructed at The Rice Institute. The magnet has been used to study the above (d, p) reactions produced by the Rice Institute pressurized electrostatic accelerator. The energy of the incident deuterons was measured in terms of the 0.8735-Mev $F^{19}(p\,\alpha'\gamma)O^{16}$ resonance, using a zinc fluoride target 2 kev thick for the incident protons. The magnetic field of the annular magnet was both measured and held constant to ± 1.5 gauss during runs by means of a proton magnetic moment regulator designed and constructed by Mr. Richard D. Jones. The values obtained for the Q's of the above reactions are 2.732 ± 0.006, 4.591 ± 0.008, and 1.918 ± 0.008 Mev, respectively. The neutron-proton mass difference as calculated from the present data for carbon and the data given by other workers for the Q's of a closed cycle of reactions involving C^{13} and C^{13} is 0.789 ± 0.008 Mev.

[1] Buechner, Van de Graaff, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1257 (1948).

J5. The Reaction $C^{14}(p, n)N^{14}$.* W. M. PRESTON, J. J. G. MCCUE, W. D. ROSEBOROUGH, JR., AND C. GOODMAN, *M.I.T.* —The reaction $C^{14}(p, n)N^{14}$ has been studied by Shoupp[1] and the inverse reaction, $N^{14}(n, p)C^{14}$, by Johnson and Barschall.[2] Since the same levels in the compound nucleus N^{15} can be excited, one expects that the resonances in the yields of the two reactions will be identical in half-width and will occur at energies differing by the $C^{14}(p, n)N^{14}$ threshold $E_t = 0.664$ Mev.[1] We have investigated the $C^{14}(p, n)N^{14}$ yield with a resolution of about 3 kev with the following results for the positions of the resonances.

TABLE I.

(This paper) E_{max}	(Shoupp) E_{max}	(Johnson and Barschall) E_{max}	$E_{max}+0.664$
1.165	1.14	0.499	1.163
1.308	1.30	0.640	1.304
1.669	1.47?	0.993	1.657
2.081	2.05	1.415	2.079

Our agreement with Johnson and Barschall is seen to be excellent; the (p, n) yield curve looks very similar to the (n, p) yield (Fig. 3 of their article).

* This work was supported by BuShips and the ONR.
[1] Shoupp, Jennings, and Sun, Phys. Rev. **75**, 1 (1949).
[2] C. H. Johnson and H. H. Barschall, Phys. Rev. **80**, 818 (1950).

J6. Excited States of N^{15} and F^{19} from $C^{12}(\alpha\, p)N^{15}$ and $O^{16}(\alpha\, p)F^{19}$.* M. L. BULLOCK, W. O. MCMINN, V. K. RASMUSSEN, AND M. B. SAMPSON, *Indiana University.*—Protons produced by the bombardment of carbon and oxygen with the external 21-Mev cyclotron α-beam were observed at 90°. Particle energies were obtained from the range in aluminum using a proportional counter biased to count only those protons near the end of their range. The carbon targets were a 0.7 mg/cm^2 Aquadag film and C_2H_4 gas. If the observed proton groups are attributed to $C^{12}(\alpha\, p)N^{15}$, they give the ground state of N^{15} and excited levels at 5.4 and 6.5 Mev, corresponding to the known[1] levels at 5.3 and 6.3 Mev. The oxygen target was research grade oxygen gas from the Matheson Company. The four proton groups observed, if attributed to $O^{16}(\alpha\, p)F^{19}$, correspond to the ground state of F^{19} and excited levels at 1.4, 2.7, and 3.8 Mev. The first two levels have been previously reported.[1,2]

* This work was assisted by the joint program of the ONR and AEC.
[1] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).
[2] M.I.T. Progress Report, July 1, 1950, p. 169.

J7. Alpha-Groups from $Al^{27}(d, \alpha)Mg^{25}$.* EDWARD C. TOOPS, FREDERICK E. STEIGERT, AND MILO B. SAMPSON, *Indiana University.*—The $Al^{27}(d, \alpha)Mg^{25}$ reaction has been investigated at 90° and 124° with Eastman NTA nuclear track plates. Magnetically analyzed 10.8-Mev deuterons bombarded a thin (0.17 mg/cm^2) aluminum target. Analyses of 3500 alpha-tracks at 90° gives eighteen well-defined groups. At 124°, 1500 tracks give sixteen groups. The Q values of groups one to eleven, in the range 6.58 to 0.63 Mev, check with previous proportional counter work at various angles.[1] Q values of -0.44, -1.16, -1.54, -1.91, -2.37, -3.06, and -3.85 Mev may be assigned to groups twelve through eighteen. A complete energy level diagram will be presented.

* This work was assisted by the joint program of the ONR and AEC.
[1] Schelberg, Sampson, and Cochran, Phys. Rev. **80**, 574 (1950).

J8. Magnetic Analysis of $Al^{27}(d, p)Al^{28}$ Reaction.* H. A. ENGE.** *M.I.T.*—The existence of an excited state at 31 kev in Al^{28} has been previously reported.[1] While bombarding thin aluminum targets with 2.0- and 1.8-Mev deuterons, more than thirty other relatively intense proton peaks have been observed that can be assigned to the $Al^{27}(d, p)Al^{28}$ reaction. Most of the peaks form clusters, the average peak separation being about 60 kev, although separations as low as 13 kev have been measured. In addition, considerable low yield structure has been observed, indicating that the energy spectrum of Al^{28} is far more complicated than previously anticipated. The Q-values of the twenty-eight most intense groups are, 5.494, 5.463, 4.479, 4.127, 3.869, 3.357, 3.296, 3.226, 3.010, 2.916, 2.842, 2.514, 2.036, 1.967, 1.621, 1.562, 1.463, 0.809, 0.735, 0.595, 0.366, 0.392, 0.405, 0.059, -0.241, -0.298, -0.361, -0.817, accurate to 10 kev or less. The observed level scheme of Al^{28} is in good agreement with that found by previous workers as far as the positions of the clusters are concerned.

* This work has been assisted by the joint program of the AEC and ONR.
** On leave of absence from the University of Bergen, Bergen, Norway.
[1] Enge, Van Patter, Buechner, and Sperduto, Phys. Rev. **81**, 317 (1951).

J9. Neutrons from Deuterons on Si^{29}.* C. P. SWANN AND AND C. E. MANDEVILLE, *Bartol Research Foundation.*—A thick target of $Si^{29}O_2$ (isotopic concentration 69 percent) has been irradiated by deuterons at 1.4 Mev supplied by the Bartol van de Graaff statitron. Recoil protons knocked on in the forward direction by neutrons from $Si^{29}(D, n)P^{30}$ were observed in photographic plates making angles of zero and 90 degrees with the incident deuterons. *Tentative* Q-values are 0.02, 1.70, 2.90, and 3.60 Mev. The data will be correlated with results obtained from $Si^{28}(D, n)P^{29}$ and $Si^{30}(D, n)P^{31}$.

* Assisted by the joint program of the ONR and AEC.

J10. An Investigation of the $Si^{29}(d, \alpha)Al^{27}$ and $Si^{29}(d, p)Si^{30}$ Reactions.* D. M. VAN PATTER, A. SPERDUTO, AND H. ENGE,** *M.I.T.*—Silicon-dioxide targets enriched in the Si^{29} isotope have been bombarded by 1.8-Mev deuterons, and the emitted proton and alpha-particle groups have been analyzed by a high resolution magnetic spectrograph. From a comparison with the groups observed from a natural SiO_2 target, a number of groups have been assigned to the Si^{29} isotope. The measured Q-values for five previously unreported $Si^{29}(d, \alpha)Al^{27}$

alpha-groups are, 5.99, 5.13, 4.97, 3.87, and 3.27 Mev, corresponding to the ground state and four excited states of Al^{27}. Six $Si^{29}(d, p)Si^{30}$ proton groups having Q-values of 8.39, 6.14, 4.87, 4.60, 3.31, and 2.77 Mev, have been tentatively identified, corresponding to the ground state and five excited states of Si^{30}. These Q-values are considered to be reliable to 20 kev. Several less intense groups have not yet been identified. The possibility that some of the observed groups may have additional structure is being investigated. (The silicon isotopes were obtained from the Stable Isotopes Division, AEC, Oak Ridge.)

* This work has been supported by the joint progran of the ONR and AEC.

** Now on leave from the University of Bergen, Bergen, Norway.

J11. The (p, n) Reaction on Separated Isotopes of Chromium.* J. J. G. McCUE, J. A. LOVINGTON, AND W. M. PRESTON, *M.I.T.*—We have measured the relative neutron yield from thin chromium targets, enriched, respectively, in Cr^{52} and Cr^{54}, as a function of proton energy in the range 1.5 to 2.5 Mev. The (p, n) threshold is about 2.2 Mev for Cr^{54} and below 1.5 Mev for Cr^{52}. In this region, most of the resonance levels in the compound nuclei Mn^{54} and Mn^{55} seem to be resolved with targets 2 to 3 kev thick. Just above $E_p = 2.2$ Mev, the spacing of virtual levels is about 5 kev for Mn^{54} and 8 kev for Mn^{55}. Using the best estimates available for the neutron binding energies, it appears that the level spacing in Mn^{54} (an odd Z-odd N nucleus) is substantially less than in Mn^{55} (an odd Z-even N nucleus) when measured at equal energies of excitation above the ground state.

* This work was supported by the Bureau of Ships and the ONR.

J12. Excitation Function of $Au^{197}(d, p)Au^{198}$ and $Au^{197}(d, 2n)Hg^{197}$.* K.-H. SUN, F. A. PECJAK AND B. JENNINGS, *Westinghouse Research Laboratories* AND A. J. ALLEN AND J. F. NECHAJ, *University of Pittsburgh*.—A ten-minute bombardment of the mono-isotopic element gold with 15-Mev deuterons yields activities with 2.7d and 1.0d half-lives by the reactions $Au^{197}(d, p)Au^{198}$ and $Au^{197}(d, 2n)Hg^{197}$. Hg^{197} is known to have an isomer Hg^{197m}, which also emits soft internal conversion electrons and has a half-life identical with $Au^{198}(2.7d)$. By absorption studies and the technique of half-life peeling, it is possible to separate the yields of the Au^{198}, Hg^{197}, and Hg^{197m}. The standard stack foil method, with 0.0007" Au foils, was used in the excitation study. The yield of the $Au^{197}(d, p)Au^{198}$ reaction started at 8-Mev deuteron energy, increased rapidly at 10 Mev, and reached a maximum at about 14.3 Mev. For the $Au^{197}(d, 2n)Hg^{197}$ reaction, the yield started at 9 Mev, increased rapidly at 10 Mev, and continued, with no sign of leveling off, at 15 Mev. The relative yield of $Au^{197}(d, p)Au^{198}$ and $Al^{27}(d, p\alpha)Na^{24}$ was also measured.

* Assisted by the joint program of the ONR and AEC.

J13. Capture of Electrons by Protons Traversing Hydrogen Gas. H. KANNER AND F. L. RIBE, *University of Chicago*.—Using the proton beam from a high voltage accelerator, the electron-capture cross section for protons in hydrogen gas has been measured at energies between 34 and 149 kev. The protons entering a chamber which could be filled with hydrogen were bent by a magnetic field into a detector. As gas was admitted and capture processes occurred, some of the protons were neutralized and did not follow a circular path to the detector. From the attenuation of the proton beam with gas pressure, the capture cross sections σ_c were derived. σ_c has the values 1.52×10^{-16} and 2.30×10^{-16} cm² at the limiting energies given above. The limiting value of the ratio n_+/n_0 (protons to atoms) attained after traversal, at constant velocity, of hydrogen gas is given by σ_i/σ_c, where σ_i is the electron loss cross section for hydrogen atoms.[1] Direct measurement of this ratio agreed with the individual cross sections of these measurements, and those of Montague *et al.*, to 10 percent. n_+/n_0 is unity in hydrogen at a velocity of 1.44 Bohr units ($e^2/\hbar$), which may be compared with the traversal of metals by protons, for which $n_+/n_0 = 1$ is attained at 0.95 Bohr unit.[2]

[1] Allison, Montague, and Ribe, Phys. Rev. **81**, 294 (1951).
[2] T. A. Hall, Phys. Rev. **79**, 504 (1950).

FRIDAY MORNING AT 10:00

NBS, Materials Testing

(J. B. NICHOLS presiding)

Session of the Division of High-Polymer Physics

Invited Paper

JA1. Studies of High Polymers by Nuclear Absorption. R. S. CODRINGTON, F. McCAFFREY, B. A. MROWCA, AND E. GUTH, *University of Notre Dame*. (30 min.)

Contributed Papers

JA2. Nuclear Magnetic Resonance Absorption in Proteins. T. M. SHAW AND K. J. PALMER, *Western Regional Research Laboratory*.—Nuclear magnetic absorption has been observed for hydrogen nuclei in wool, horn, silk, egg albumin, collagen, gelatin, glycine, and a number of other solids. For the proteins, the absorption, observed at 25°C and a relative humidity of about 40 percent, consists of a single line of complex shape. The line appears to consist of a narrow peak superimposed symmetrically on a broad band. Step-wise removal of water from the proteins results in corresponding reduction in amplitude and finally the disappearance of the narrow line. A line width of approximately 6 gauss was obtained for thoroughly dried horn keratin. In general, lines observed for temperatures near 100°C are slightly narrower than for 25°C. For callogen, however, heating causes thermal contraction and the line width at 100°C is much narrower than at 25°C. Upon cooling to 25°C the resonance line broadens and is indistinguishable from that observed for unheated collagen. The correlation between line width of the resonance absorption peak and crystallinity as determined by x-ray diffraction has been made for several of the proteins studied.

JA3. The Three-Dimensional Patterson Function of Air-Dried Lysozyme Chloride. ROBERT B. COREY, JERRY DONO-

HUE, AND KENNETH N. TRUEBLOOD, *California Institute of Technology*, AND KENNETH J. PALMER, *Western Regional Research Laboratory*.—Quantitative x-ray data for all CuK_α reflections from crystals of air-dried lysozyme chloride have been collected at the Western Regional Research Laboratory. About 650 spots corresponding to 200 separate forms of (*hkl*) were indexed and their intensities visually estimated. The minimum spacing observed was about 6A. These data have been used at the California Institute of Technology to calculate the three-dimensional Patterson function. The conspicuous maxima of this function may be divided into two general classes: first, those which occur within about 12A of the origin and are probably associated with intramolecular interactions, and, second, those which occur beyond 20A and are probably associated with intermolecular distances within the crystal. An interpretation of the details of the Patterson function indicates that regions of relatively high density are to be found at the following positions in the unit cell: $x=0.27$, $y=0.44$, $z=0.25$; $x=0.24$, $y=0.36$, $z=0.00$; and equivalent positions.

JA4. Dynamic Shear Properties of Isobutylene Polymers as a Function of Cross-Linking. I. L. HOPKINS, *Bell Telephone Laboratories* (Introduced by W. O. BAKER).—Recent developments in the technique of measuring the dynamic shear properties of rubber-like polymers by means of tuning forks will be described. Results of the application of this technique to non-cross-linked, cross-linked, and loaded polyisobutylene within a frequency range of 0.1 to 13.7 kc will be described. Within this range both G' and G'' increase approximately with the square root of the frequency, with the proportionality factor increasing with cross-linking and loading. The functional relationship between modulus and chain length between cross links is discussed, and compared with that found by Flory[1] for static conditions.

[1] Paul J. Flory, Ind. Eng. Chem. **38**, 417 (1946).

JA5. Energy Dissipation in Vibrating Fibers. W. G. HAMMERLE AND D. J. MONTGOMERY, *Textile Research Institute*.—Experiments on energy dissipation in fibers at small amplitudes of stretching vibration have shown a dependence of dissipation on frequency that has not been explained on the basis of either Newtonian linear or Eyring nonlinear damping. On the other hand, for many rather highly crystalline materials, the classical viscous explanation does appear adequate. In an attempt to explain the observed frequency dependence for both classes of materials, we have investigated the dissipation per cycle of sinusoidal longitudinal vibration. Preliminary calculations indicate that for materials with large intermolecular binding energies, the dissipation per cycle is proportional to frequency, in conformity with the classical theory. We are in process of evaluating the dissipation for materials where the binding energies are relatively small. The dissipation per cycle, in any case, turns out to be proportional to the square of the amplitude. We have not yet completed evaluation of the temperature dependence. In materials where entropy forces are small compared with internal energy forces, such as in crystals and highly cross-linked polymers, our results indicate a correlation of the elastic modulus with dissipation in substances of the same general type. However, experimental data are not yet sufficiently plentiful to make suitable comparison possible.

JA6. The Application of Nutting's Equation to the Viscoelastic Behavior of Certain Polymeric Systems. ROLF BUCHDAHL AND LAWRENCE E. NIELSEN, *Monsanto Chemical Company*.—The Nutting equation $-\epsilon=\psi\times\tau^{\beta}\times t^{n}$, where ϵ=strain, τ=stress, t=time and ψ, β, and n are material constants, is applicable to a large number of polymeric systems, such as plasticized polyvinyl chloride, styrene-butadiene copolymers, polystyrene, etc. It has been shown that the material constant n, which determines essentially the time dependence of the deformation process, is closely related to the damping coefficient as obtained from dynamic mechanical measurements: the temperature dependence of n and δ (damping coefficient) are about the same; and, in some cases, there exists a simple quantitative relationship between the two constants. Furthermore, it has been shown that in the case of styrene-butadiene copolymers n varies with the differences in gel content and gel structure. For semipermanent gel structures, such as exist in polystyrene above the second-order transition point, n becomes a function of time, as would be expected. Over a wide stress range, there also appears to be a dependence of n on stress and the significance of this relationship with respect to the stress dependence of the damping coefficient is discussed briefly.

JA7. Flow Behavior of Highly Concentrated Cetane Solutions of Low Molecular Weight Polyisobutylenes.* A. B. BESTUL AND H. V. BELCHER, *National Bureau of Standards*.—Flow measurements were made with the McKee worker-consistometer on cetane solutions of 10, 30, 50, 70, and 90 weight percent of four polyisobutylenes with viscosity average molecular weights between 50,000 and 100,000 and on the bulk polymers. Measurements were made on all solutions at 100°F and on the bulk polymers at 100°, 200°, and 300°F. The results cover rates of shear ($\dot{\gamma}$) from 20 to 200,000 sec^{-1} and shearing stresses (s) from 2000 to 5,000,000 $dynes/cm^2$. For concentrations up through 50 percent the relation $\dot{\gamma}=(\text{const}_1)s+(\text{const}_2)s^3$ appears reasonably suitable for extrapolating the results to zero shearing stress. For higher concentrations, including the bulk polymers, the relation $\dot{\gamma}=(\text{const}_1)s+(\text{const}_2)s^3$ is preferable. No previously proposed flow relation is valid over the total range of the data. The temperature variation of the ratio $s/\dot{\gamma}$ (viscosity) for the bulk polymers at constant s remains nearly constant as s is increased from zero; however, this variation at constant $\dot{\gamma}$ decreases as $\dot{\gamma}$ is increased from zero.

* The work reported here was supported by the Reconstruction Finance Corporation, Office of Rubber Reserve.

JA8. The Behavior of Macromolecules in Sedimentation and Diffusion. F. R. EIRICH AND H. F. MARK, *Polytechnic Institute of Brooklyn*.—The diffusion and sedimentation of colloidal electrolytes and proteins has received detailed theoretical and experimental attention, although usually conditions were applied under which charge effects are suppressed. In electrically charged chain molecules the ordinary charge effects tend to be overshadowed by the effects of the accompanying shape changes. In ultracentrifugation the situation is complicated by both influences occurring to a comparable extent. We have tried to clarify the situation by suitable variations of polymer and electrolyte concentration. Preliminary results indicate that, if shape changes are assumed as they can be calculated from viscosity behavior, reasonable charges for the polymer molecules follow. The influence of ions of the same sign as the chain molecule has also been investigated.

JA9. Densities and Optical Properties of High Polymers. MAURICE L. HUGGINS, *Eastman Kodak Company*.—Equations and constants deduced from data on simple organic liquids are used to compute densities, refractive indices, and optical dispersions which high polymers would have if they were liquid. Corrections for rigidity, crystallinity, and the presence of plasticizers and solvents are discussed. Comparisons are made with experimental data, where available.

FRIDAY MORNING AT 9:45

Shoreham, West Ballroom

(M. L. POOL presiding)

Radioactive Nuclei, Tritium through Cerium; Neutrinos

K1. Limit on Neutrino Mass from Tritium Beta-Spectrum. DONALD R. HAMILTON, W. P. ALFORD, AND LEONARD GROSS,* *Princeton University.*—A hemispherical electrostatic integral beta-spectrograph[1] (energy resolution 120 volts at 20 kilovolts) has been used to investigate the tritium spectrum[2] near the end point. The strongest source used (tritium in zirconium) has essentially infinite thickness for tritium electrons. The spectrum of this source is distorted at voltages more than 1.5 kilovolts below the end point; to within experimental error the spectrum for the last 1.5 kilovolts agrees with that to be expected for zero neutrino mass; preliminary results give (neutrino mass) $\leqslant$ 250 electron volts = (electron mass)/2000. A thinner and less intense source gives an undistorted spectrum down to 10 kilovolts and (neutrino mass) $\leqslant$ 500 volts. The end point is found to be 19.4±0.4 kilovolts, the uncertainty arising in the absolute voltage calibration. This work has been supported in part by the joint program of the ONR and AEC and by the Eugene Higgins Scientific Trust Fund. Tritium was obtained from the AEC.

* AEC Predoctoral Fellow, 1948–49.
[1] D. R. Hamilton and L. Gross, Rev. Sci. Instr. **21**, 912 (1950).
[2] Curran *et al.*, Phil. Mag. **40**, 53 (1949). G. C. Hanna and B. Pontecorvo, Phys. Rev. **75**, 983 (1949).

K2. Beta- and Gamma-Radiation of Al^{28} and the Mass of Al^{27}.* H. T. MOTZ, *Brookhaven National Laboratory.*—The spectrum of 2.3-minute Al^{28} has been studied using samples activated in the Brookhaven nuclear reactor and a lens spectrometer with a resolution of 2 percent. A gamma-ray energy of 1.785±0.015 Mev has been found by external conversion in a uranium foil. The beta-spectrum from a 2-mg/cm² source has been fitted to a Kurie plot for an allowed transition from approximately 1 Mev to the end point. The end point has been found to be 2.83±0.03 Mev. No beta-transition to the ground state of Si^{28} has been observed. Such a transition is less than 2 percent of the observed beta-decay to the excited state. These results are in general agreement with previous studies of Al^{28}. The observed total disintegration energy of 4.615 ±0.035 Mev does not agree with the writer's calculations of the Al^{28} and Si^{28} masses,[1] but is in good agreement with recent reaction data obtained at MIT.[2] A more consistent set of masses from Ne^{20} to S^{32} results from an Al^{27} mass approximately 0.2 mmu higher than the value 26.989 83±0.000 08 given by Ewald and Mattauch,[3] which was used in reference 1.

* Research carried out under contract with AEC.
[1] H. T. Motz, Phys. Rev. **81**, 1060 (1951).
[2] D. M. Van Patter (private communication).
[3] J. Mattauch and H. Ewald, Physik. Z. **44**, 181 (1948).

K3. A 25-Day Activity in P^{32} Samples.* ERLING N. JENSEN AND R. T. NICHOLS, *Iowa State College.*—The radiations from P^{32} have been examined with a thin magnetic lens spectrometer. The maximum energy of the 14.3-day beta-activity was determined as 1.704±0.008 Mev. An additional beta-activity has been observed in three separate $S^{32}(n, p)P^{32}$ shipments from Oak Ridge, though it was masked for the first two or three weeks by the 14.3-day activity. From seven beta-spectra taken of one sample, over a period of 144 days, the half-life was found to be 26±3 days and the maximum beta-energy 0.26±0.02 Mev. It is estimated that the 25-day activity formed about one percent of the initial activity of the sample. Using a sample which had decayed for 10 months, at which time the unknown activity was estimated to be more than 90 percent of the total activity, a half-life of 25.2±0.5 days was measured. A similar activity has been observed in the beta-spectra of a source from a $P^{31}(n, \gamma)P^{32}$ reaction. These data, on the low energy beta-activity, are in disagreement with the results of Agnew[1] and Warshaw, Chen, and Appleton.[2]

* This work was performed at the Ames Laboratory of the AEC.
[1] H. M. Agnew, Phys. Rev. **77**, 655 (1950).
[2] Warshaw, Chen, and Appleton, Phys. Rev. **80**, 288 (1950).

K4. The Nuclide P^{33}. R. K. SHELINE, R. B. HOLTZMAN, AND C. Y. FAN, *University of Chicago.*—P^{33} has been produced by the bombardment of sulfur, sodium sulfide, and lithium chloride with 48-Mev gamma-rays produced by the University of Chicago betatron. The reactions involved are $S^{34}(\gamma, p)P^{33}$, $Cl^{35}(\gamma, 2p)P^{33}$, and $Cl^{37}(\gamma, \alpha)P^{33}$. The phosphorus was separated as the phosphomolybdate and as the magnesium ammonium phosphate. The P^{33} activity has a 25±2-day half-life with a 0.25±0.01-Mev negative beta-ray. There is less than 0.1 (0.5 Mev) gamma per beta. The activity was observed in the presence of P^{32}, and its ratio to the P^{32} activity did not change with chemical purification. The Fermi plot of the beta-ray spectrum was straight with a log*ft* value of 5.1.

K5. Neutrino Recoils Following the Capture of Orbital Electrons in A^{37}. G. W. RODEBACK AND J. S. ALLEN, *University of Illinois.*—An improved apparatus for studying the recoil nuclei following the disintegration of A^{37} through the capture of orbital electrons has been constructed. Two electron multipliers placed at 90° with respect to each other define the effective volume of the gaseous source. The velocity of the recoil ions is studied by measuring their time-of-flight over an average distance of 5 cm between the source volume and the ions counter. Our experimental results give two well-defined peaks of coincidence counting rate *versus* delay time. The first peak extends from zero time to about 1 microsecond with the same magnitude as the second peak. The origin of the first peak is being investigated. Both the position and the width of the second peak correspond closely to the values expected for the 9.7-electron volt recoil ions originating in the source volume and predicted by conservation of momentum and energy in the A^{37} decay process. No additional recoils have been observed out to a delay time 6 times that of the second peak.

K6. Radioactive A^{39} from $A^{40}(\gamma, n)$ Reaction.* MARVIN HOFFMAN, *Iowa State College* (introduced by L. J. LASLETT).—Natural argon gas was irradiated in the x-ray beam of the 70-Mev synchrotron. The bombarded gas was then used as filling gas for a Geiger counter and counted; thus, no low energy radiation might go unobserved. Data taken in this manner compare with that taken by surrounding a thin-wall glass counter with the bombarded gas. Activities attributable to Cl^{39}, Cl^{38}, and a 145±15-sec activity were observed. Assigning[1] the 145-sec activity to A^{39}, all expected activities are observed and accounted for.

* Work was performed at the Ames Laboratory of the AEC.
[1] A. Zucker and W. W. Watson, Phys. Rev. **80**, 966 (1950).

K7. Beta-Spectrum of Fe^{55}. F. I. BOLEY* AND L. J. LASLETT, *Iowa State College.*†—Fe^{55} (8.9 min) has been prepared by irradiation of a 1-mil iron foil in the Iowa State College synchrotron and the positron spectrum examined with a scintillation spectrometer. Pulse heights were recorded photographically and the 0.62-Mev internal-conversion line from Cs^{137} used for calibration. A Kurie plot of the data leads to an end-

point of 2.5±0.1 Mev. The spectrum appears to be of the first-forbidden type ($Fl=\pm 5.4\times 10^4$ sec), for which the "a" correction of Konopinski[1] is appropriate. The forbidden shape is corroborated by comparison spectra obtained with Y^{90} and P^{32} sources, the Y^{90} requiring the "a" correction, while the P^{32} data do not. Corrections for the finite resolution of the instrument[2] have been applied to all data.

* Socony-Vacuum Research Fellow.
† This work was performed in the Ames Laboratory of the AEC.
[1] E. J. Konopinski, Revs. Modern Phys. 15, 209 (1943).
[2] J. P. Palmer and L. J. Laslett, to be published.

K8. Radioactivity of Tc^{93}, Tc^{96}, Tc^{98}, and Tc^{101}. G. E. Boyd and B. H. Ketelle, *Oak Ridge National Laboratory.*—The disintegrations of 2.75-hr Tc^{93}, 60-d Tc^{96}, 4.20-d Tc^{98}, and 13.5-min Tc^{101} were studied using a magnetic lens beta-spectrometer, a gamma-scintillation spectrometer, and coincidence methods. The positron spectrum of Tc^{93} is simple with an end point of 0.800±0.005 Mev followed by a 1.32-Mev gamma-ray. Tc^{93} decays largely (α 90 percent) by orbital electron capture followed by a 2.20-Mev gamma-ray. No 6.7-hr Mo^{93} daughter activity resulted from the 2.75-hr Tc. Good photo-peaks showing gamma-rays of 0.20, 0.58, 0.80, and 1.03 Mev in the 60-d Tc^{96} were observed in agreement with recent spectrometer measurements.[1] Observations on the gamma-spectrum of the 4.20-d Tc^{98} also confirmed Medicus, *et al.* In addition, low intensity lines at 1.65, 1.89, and 2.39 Mev were found which may arise from cross-over transitions. The gamma-ray spectrum of 13.5-min Tc^{101} consists of a strong line at 0.30 together with a weaker line at 0.56 Mev, and one or more lines of very low intensity at slightly higher energy. Coincidence counting showed that over 95 percent of the disintegrations of Tc^{101} proceed through a 1.20±0.05-Mev beta followed by the 0.30-Mev gamma. No short-lived isomer could be found.

[1] Medicus, Preiswerk, and Sherrer, Helv. Phys. Acta 23, 299 (1950).

K9. Cross-Over Transition in Tc^{99m}. J. W. Mihelich, M. Goldhaber, and Elizabeth Wilson,* *Brookhaven National Laboratory.*—Medicus, Maeder, and Schneider[1] have shown that Tc^{99m} (6 hr) decays in two steps: A (1.8±0.3)-kev transition followed by a (141.2±0.5)-kev transition with the latter identified from its K-conversion coefficient as a magnetic dipole transition. We have found the expected cross-over transition by photographing the internal conversion electrons from a thin Tc^{99m} source in a high resolution 180° magnetic beta-spectrograph. Two K and L lines were observed, corresponding to γ-rays of 140.1±0.5 kev and 142.1±0.5 kev. The difference is 2.0±0.1 kev. From the relative intensity of the electron lines the cross-over transition can be estimated to take place in about 1 percent of the disintegrations and can be assigned to a $p\,1/2 \rightarrow g\,9/2$ transition (2^4 magn). The small energy difference between the $g\,9/2$ ground state and the 7/2+excited state, as well as a still smaller difference (9.3 kev) observed by Bergström[2] for Kr^{83} can be interpreted by assuming that the $(g\,9/2)^3$ or ^{7} configurations have two low lying states: 7/2+ and $g\,9/2+$.

* Research carried out under contract with the AEC.
[1] Medicus, Maeder, and Schneider, Helv. Phys. Acta 22, 603 (1949); Phys. Rev. 81, 652 (1951).
[2] I. Bergström, Phys. Rev. 81, 638 (1951).

K10. Classification of Nuclear Isomers.* A. W. Sunyar and M. Goldhaber, *Brookhaven National Laboratory.*—Nuclear isomers have been reclassified and the following conclusions reached. The lifetime-energy relations of Axel and Dancoff[1] and the K/L ratios calculated by Hebb and Nelson[2] yield spin differences which are one unit too high for electric 2^3 and 2^4 transitions. Electric 2^3 transitions are 100 or more times slower than expected from Weisskopf's formula.[3] Electric 2^4 and 2^5 transitions are also slower than given by Weisskopf, but very few examples are known. Magnetic 2^4 transitions agree very well with Weisskopf's formula. For these transitions, K/L ratios are lower than calculated by Tralli and Lowen.[4] This discrepancy cannot be explained by admixture of electric 2^5 transitions. The isomeric transitions in the $g\,9/2$ shell, previously assigned no parity change, are explained as electric 2^3. This is interpreted by assuming that for the configurations $(g\,9/2)^{3,5 \text{ or } 7}$, 7/2+ and $g\,9/2$ states are comparable in energy. The 7/2+ state is lower in nearly half the cases.

* Research carried out under contract with the AEC.
[1] P. Axel and S. M. Dancoff, Phys. Rev. 76, 892 (1949).
[2] M. H. Hebb and E. Nelson, Phys. Rev. 58, 486 (1940).
[3] See R. D. Hill, Phys. Rev. 81, 470 (1951).
[4] N. Tralli and I. S. Lowen, Phys. Rev. 76, 1541 (1949).

K11. Gamma-Rays Emitted in the Disintegration of the 36-hr Rhodium (105).* C. E. Mandeville and E. Shapiro, *Bartol Research Foundation.*—Earlier measurements[1,2] have indicated a gamma-ray at ~0.3 Mev in the decay of Rh^{105} (36 hr). More recent data[3] seem to show the absence of gamma-rays. Consequently purified metallic ruthenium was irradiated for ten hours by slow neutrons in the Oak Ridge pile, and the radiations of Rh^{105}, grown from its 4.5-hr ruthenium parent, were reinvestigated. After irradiation, the rhodium was separated from ruthenium by distillation of RuO_4 from a perchloric-sulfuric acid solution. The gamma-ray activity was followed for three half-periods, and the observed half-life was 35±1 hr. Lead absorption curves at time zero and forty hours later yielded a quantum energy of 0.3 Mev. Comparative measurements with the beta-spectrum of the 5-day Bi^{210} showed that bremsstrahlung effects were negligible.

* Assisted by the joint program of the ONR and AEC.
[1] Sullivan, Sleight, and Gladrow, Plutonium Project Report CC-1493 (1944).
[2] C. E. Mandeville and E. Shapiro, Phys. Rev. 80, 125 (1950).
[3] R. B. Duffield and L. M. Langer, Phys. Rev. 81, 203 (1951).

K12. Nuclear Spectra of Ba^{131} and Cs^{131}.* Robert Canada and A. C. G. Mitchell, *Indiana University.*—The nuclear spectra of Ba^{131} and Cs^{131} were measured in a magnetic lens spectrograph. Both elements decay by orbital electron capture. The sources were prepared by the irradiation of barium with neutrons in the Oak Ridge Pile. Barium was separated chemically, and the daughter cesium was separated by ion column techniques. The spectrum of Ba^{131} consisted of gamma-rays at 122, 196, 213, 241, 371, and 497 kev. Cs^{131} exhibits no gamma-rays or positrons. The particle spectrum consists of Auger electrons only. No lines corresponding to the 163-kev level of the 12-d metastable Xe^{131} or the 80-kev state of Xe^{131} were found.

* Supported by the joint program of the ONR and AEC.

K13. Gamma-Rays in the Decay of the Radio-Isotopes of Cerium.* H. B. Keller† and J. M. Cork,‡ *Argonne National Laboratory.*—The enriched isotopes of cerium were obtained from the Isotope Division of the Oak Ridge National Laboratory and bombarded in the Argonne heavy water moderated nuclear reactor. The activities thereby induced were examined for conversion electrons in a permanent magnet-type, photographic beta-spectrometer. The gamma-rays deduced from the experimental data are summarized below:

Radio-isotope	Gamma-rays (kev)	Mode of decay	Half-life
Ce^{137}	253.4	K capture	36 hr
Ce^{139}	166.0; 275.2	K capture	140 d
Ce^{141}	145.7		28 d
Ce^{143}	57.5; 290.6; 348.4	β	33 hr
Ce^{144}	34.0; 41.3; 46.8; 53.7 80.9; 95.0; 100.5; 134.5	β	300 d
Pr^{144}	61.0	β	17.5 min

Decay schemes will be proposed.

* Supported in part by the joint program of the ONR and AEC.
† Phoenix Project Fellow, University of Michigan.
‡ University of Michigan.

FRIDAY MORNING AT 9:45

Shoreham, Main Ballroom

(C. C. LAURITSEN presiding)

Symposium on Stable Isotopes

L1. A Review of the Production and Uses of Stable Isotopes Enriched Electromagnetically from 1945 to 1951. C. P. KEIM, *Oak Ridge National Laboratory.* (35 min.)

L2. Contributions of Stable Isotopes to Atomic Spectroscopy. J. R. MCNALLY, JR., *Oak Ridge National Laboratory.* (35 min.)

L3. Uses of Stable and Enriched Isotopes in the Study of Artificially-Produced Radioisotopes. M. L. POOL AND D. N. KUNDU, *Ohio State University.* (30 min.)

L4. Recent Developments in Mass Spectroscopy. A. O. C. NIER, *University of Minnesota.* (35 min.)

FRIDAY MORNING AT 9:45

Wardman Park, Continental Room

(J. H. VAN VLECK presiding)

Scattering

M1. Scattering of π^+ Mesons by Carbon.* M. SKINNER AND C. RICHMAN, *University of California, Berkeley.*—A carbon target 2.7 cm thick was placed in the 54-Mev π^+ meson beam[1] of the Berkeley 184-in. synchro-cyclotron. Mesons scattered from the carbon at 90° were detected in nuclear emulsions embedded in copper absorbers. To obtain a reasonable ratio of meson to background tracks in the emulsions it was necessary to sacrifice good angular and energy resolution. Some mesons that scattered at angles as low as 60° or as high as 130° were accepted. The energy spectrum of the scattered mesons, after leaving the carbon target, is continuous from zero Mev to the maximum meson energy. By integrating the spectrum, one obtains a value for the differential scattering cross section. (This value is somewhat lower than the true differential cross section, since at any point in the carbon target there is a minimum energy which a meson must have after scattering in order to leave the carbon.) On the basis of 50 scattered mesons, this differential cross section for the scattering of 47 Mev π^+ mesons at 90° from carbon is $(2.2\pm1.0)\times10^{-28}$ cm^2 sterad^{-1}.

* This work was performed under the auspices of the AEC.
[1] Richman, Skinner, Merritt, and Youtz, Phys. Rev. **80**, 900 (1950).

M2. Scattering of π-Mesons. M. H. JOHNSON, *Naval Research Laboratory.*—The collision between a moderately energetic meson and a nucleus can be described approximately as a collision between a meson and free nucleons whose initial momentum distribution is determined by the nuclear state. Using conservation laws, the differential cross section for collisions in which the meson's vector momentum lies within a prescribed interval may then be written as an integral over a surface in the space of the relative momentum. The integrand contains the product of the differential scattering cross section and the initial momentum distribution. Portions of the surface where the nucleon's final momentum takes on values forbidden by the exclusion principle are omitted from the integration. The nuclear model in which the nucleons are a degenerate Fermi gas has been examined in detail. The exclusion principle eliminates collisions with meson energy gain and greatly reduces the number of collisions with small meson energy loss. However, an extreme variation of the scattering cross section with angle and energy is necessary to obtain a distribution, indicated by experiment,[1] in which almost all inelastic collisions occur with an energy loss greater than 80 percent.

[1] G. Bernardini, Invited Paper H3, Bull. Am. Phys. Soc. **26** (February 1–3, 1951).

M3. Multiple Scattering of Particles in Nuclear Emulsions.[1] DALE R. CORSON, *Cornell University.*—The multiple scattering of 40-, 115-, 195-, and 280-Mev electrons and positrons has been measured in *G*-5 emulsions by the Fowler[2] technique. After the "noise" has been eliminated, the mean scattering angle for a 100μ cell can be represented by $\langle\alpha(100)\rangle_{Av}=K/E$, where α is measured in degrees, E in Mev, and $K=26\pm1$. The determination of K is based on measurement of a combined total track length of 90 cm. The multiple scattering of nonrelativistic protons has been studied by calculating, for each proton track (ending in the emulsion and longer than 500μ), a parameter $P=\langle R^{0.55}\alpha(x)/x^{\frac{1}{2}}\rangle_{Av}$, where α is the scattering angle in degrees for a cell length of x microns at a residual range of R microns. For 75 proton tracks, P is measured to be 5.9 ± 1.0. For mesons, P is about 14.

[1] Assisted by the joint program of the ONR and AEC.
[2] P. H. Fowler, Phil. Mag. **41**, 169 (1950).

M4. Backscattering of Secondary Electrons.* G. J. HINE,** *M.I.T.*—The scattering of secondary electrons produced by γ-rays in materials of various atomic numbers has been studied as a function of the γ-ray energies. A collimated γ-ray beam from different isotopes passes through two square ionization chambers with extremely thin walls (0.00025" Al). By placing absorbers of various materials between the two chambers, the emission of secondary electrons in the backward and forward direction can be determined. The backscattering of Compton electrons has been found to vary as $\log(Z+1)$, where Z is the atomic number of the absorber. The same type of increase in backscattering with increasing Z of the backscattering material has been observed previously for β-rays by other investigators. In addition to the Compton electrons, the emission of photoelectrons becomes apparent in high Z materials. The emission of secondary electrons in the forward direction appears to be reduced in proportion to the backscattered intensity. Therefore, e.g., a carbon absorber irradiated with the Co^{60} γ-rays, emits more than twice as many secondary elec-

trons in the forward direction as a lead absorber. A number of practical applications which follow from this investigation will be discussed.

* This work has been assisted by the joint program of the ONR and AEC.
** Special Research Fellow of the National Cancer Institute, Bethesda, Maryland.

M5. The Evaluation of Multiple Scattering Losses in Charged Particle Experiments. W. C. DICKINSON AND D. C. DODDER,* *Los Alamos Scientific Laboratory.*—In nucleon-nucleon scattering or reaction experiments, where the nuclear particles must traverse a foil or a thick layer of gas, the net loss of particles owing to multiple scattering may not be negligible. A graphical integration method is given for the easy determination of the fractional loss of particles. The multiple scattering theory of E. J. Williams[1] is used to obtain the mean square spatial angle of multiple scattering in the foil or gas. The results obtained, using Williams' theory and the graphical method, are compared with experimental determinations of multiple scattering losses. Theory and experiment are found to be in satisfactory agreement.

* Now at the University of Minnesota.
[1] E. J. Williams, Proc. Roy. Soc. (London) **169**, 531 (1939); Phys Rev. **58**, 292 (1940).

M6. Elastic Scattering of γ-Rays by a Coulomb Field. R. GLUCKSTERN AND F. ROHRLICH, *Cornell University.*—This effect, also called Delbrück or potential scattering, was calculated for zero angle. A laborious but exact calculation by the Feynman method yields the complex scattering amplitude in terms of known functions (elliptic, etc.). It is verified that the imaginary (absorptive) part, $a_1(\omega, 0)$, is exactly $\omega/4\pi$ times the total pair production cross section.[1] Using this cross section, one can find numerically the real (dispersive) part $a_1(\omega, 0)$ by analytic continuation. The result agrees with the independently obtained exact formula for a_1. For small energies $a_1 \sim \omega^3$; for large energies, $a_1 \sim \omega$; $a_2 \sim \omega \ln\omega$. It is to be noted that a_1 is always positive, since the vacuum is able to provide an arbitrarily large number of pairs if the necessary energy is available. At threshold $a_1 = 0.069$, $a_2 = 0$; near 4 Mev a_1 and a_2 are equal. Typical values are

E	a_1	a_2	$d\sigma(0)/d\Omega$ for Pb
1.33	0.12	0.006	0.15 mb/sterad
7.0	1.9	2.9	0.12 b/sterad
200	75	395	1.6 kb/sterad

The energies are in Mev, the amplitudes in units of $(\alpha Z)^2 r_0$.

[1] Jost, Luttinger, and Slotnick, Phys. Rev. **80**, 189 (1950).

M7. Proton-Proton Scattering at 5.86 Mev.* E. J. ZIMMERMAN** AND P. G. KRUGER, *University of Illinois.*—The differential cross section for proton-proton scattering at 5.86±0.06 Mev has been measured using a scattering chamber filled with hydrogen. Proportional counters in coincidence reduced background to a negligible amount. The cyclotron beam through the scattering chamber charged a high resistance, polystyrene-dielectric condenser to a voltage accurately measured with a vibrating-reed electrometer. Twenty thousand scattered protons were counted at each angle. Errors other than statistical were estimated to be 0.7 percent, giving a total standard deviation of 1 percent for each cross section measured. Analysis of the data gives an S-wave phase shift of 55.6°±0.3° and indicates a possible P-wave phase shift of −0.36°±0.22°. The following cross sections in millibarns per steradian were obtained (center-of-mass system): 26°: 99.4; 30°: 89.3; 40°: 83.9; 50°: 83.8; 60°: 86.5; 70°: 86.9; 80°: 88.2; 90°: 87.3; 100°: 87.2; 110°: 87.7. Scattering of protons by oxygen in the same chamber gave important checks on the performance of the apparatus.

* Assisted by the joint program of the ONR and AEC.
** AEC Predoctoral Fellow, 1948–1950.

M8. Proton-Proton Scattering at 345 Mev. O. CHAMBERLAIN, E. SEGRÈ, AND C. WIEGAND, *University of California, Berkeley.*—Previously reported[1] measurements on the differential scattering cross section in elastic proton-proton collisions have been extended to include scattering at small angles from the beam. A digest of the results is contained in Table I.

TABLE I.

Angle θ C.M. system in degrees	Differential cross section C.M. system in 10^{-27} cm²/sterad	Error (Std. Deviation) in diff. cross section in 10^{-27} cm²/sterad
Using a liquid hydrogen target:		
11.3	5.2	0.5
15	3.5	0.3
21	3.3	0.3
33	3.5	0.2
43	3.4	0.2
53	3.3	0.2
Using a CH_2 target:		
36	4.1	0.3
44	4.0	0.3
46	3.8	0.2
52	3.8	0.2
61	3.8	0.3
64	3.6	0.3
71	3.7	0.2
80	4.0	0.3
88	3.7	0.2

Comparisons will be made to theoretical results of R. S. Christian, R. Jastrow, and others which involve both $n-p$ and $p-p$ scattering at high energies. Through the Radiation Laboratory, this work has been supported by the AEC.

[1] Chamberlain, Segrè, and Wiegand, Phys. Rev. **81**, 284 (1951).

M9. The Scattering of 9.7-Mev Protons by Deuterons. A. H. ARMSTRONG,* J. C. ALLRED, R. O. BONDELID, AND L. ROSEN, *Los Alamos Scientific Laboratory.*—The range and intensity distribution of 9.7±0.15 Mev protons scattered by deuterons have been investigated by means of the Los Alamos multiple nuclear-plate camera. A collimated beam of approximately mono-energetic protons was obtained from the 60-inch cyclotron of the Crocker Laboratory at Berkeley. Values of the differential elastic scattering cross section have been determined for fifty center-of-mass angles between 15° and 176°. The shape of the cross-section curve can be inferred from the following representative cross-section values in millibarns at the corresponding center-of-mass angles in degrees: 148 (30°); 97 (60°); 49 (90°); 25 (110°); 21 (120°); 26 (130°); 84 (150°); 190 (170°). The minimum of the curve lies on a continuous straight line of negative slope formed by the minima of the cross-section curves for lower energy data.

* On leave from Wellesley College, Wellesley, Massachusetts.

M10. Elastic Proton-Deuteron Scattering at 240 Mev.* R. D. SCHAMBERGER, *University of Rochester.*—The internal proton beam of the 130″ Rochester synchro-cyclotron has been used to measure the elastic proton-deuteron cross section. The apparatus includes two scintillation counters to detect the protons and deuterons scattered from a heavy paraffin target, and the associated electronics to record the singles and coincidence rates. The cross section relative to the $C^{12}(p, pn)C^{11}$ cross section is obtained by measuring the C^{11} beta-activity of the target. With the present apparatus, measurements are feasible for a limited range of scattering angles. The laboratory scattering angle for the proton must be greater than 12° to permit detection of the low energy deuteron. The upper limit on the scattering angle will be determined by the magnitude of the cross section. A laboratory cross section of less than 2 mb/sterad at a proton scattering angle of 45° would be very difficult to measure. Data will be presented on the cross section in this angular range.

* Assisted by the joint program of the AEC and ONR.

M11. The Elastic Scattering of Protons by Mg^{24}.*,† F. P. MOORING, E. GOLDBERG, S. G. KAUFMANN,‡ L. J. KOESTER,‖ AND D. SAXON, *University of Wisconsin.*—Protons from the electrostatic generator were used to bombard thin $Mg^{24}F_2$ targets evaporated onto spectroscopically pure graphite backings, and the elastically scattered protons were observed at a laboratory angle of 164±5°. A 90° magnetic analyzer separated the proton groups, and a proportional counter distinguished between proton pulses and fluorine alpha-pulses. The elastic differential scattering cross-section curve for incident proton energies of 0.396 to 3.936 Mev shows nine levels of the compound nucleus Al^{25}. The level reported by Grotdal, *et al.*,[1] for 0.417 Mev protons was not observed. The elastic scattering yield below 0.8 Mev was assumed to be Rutherford and was used to determine differential scattering cross-section values.

* Work supported by the AEC and the Wisconsin Alumni Research Foundation.
† Mg^{24} was produced by the Y-12 Plant, Carbide and Carbon Chemicals Corporation, on allocation from the Isotopes Division of the AEC.
** Now at Fairchild Engine and Airplane Corporation, Oak Ridge, Tennessee.
‡ Now at Argonne National Laboratory, Chicago, Illinois.
‖ AEC Predoctoral Fellow.
[1] Grotdal, Lönsjö, Tangen, and Bergström, Phys. Rev. **77**, 296 (1950).

M12. Elastic Scattering of Protons by Mg^{24};* Interpretation of Results.† L. J. KOESTER,‡ E. GOLDBERG, S. G. KAUFMANN, F. P. MOORING, AND D. SAXON, *University of Wisconsin.*—Of the nine resonances mentioned in the preceding abstract, seven are narrow and well separated, while the remaining two are broad and overlap some of the others. Momentum analyses taken in the vicinity of several of the higher resonances indicate that the partial width for inelastic scattering is relatively small. A complete analysis of the data is in progress in which the phase shift at a given energy is separated into a resonance term and a potential term. Assuming a value for the interaction radius, one can use coulomb wave functions to compute the phase shift owing to potential scattering for each partial wave. Effects of overlapping levels are considered. A graphical method is used to combine the Rutherford, resonance, and potential contributions to the scattered amplitude.

* Mg^{24} was produced by the Y-12 Plant, Carbide and Carbon Chemicals Corporation, on allocation by the Isotopes Division of the AEC.
† Work supported by the AEC and the Wisconsin Alumni Research Foundation.
‡ AEC Predoctoral Fellow.

M13. Theory of Multiple Scattering, Particularly of Electrons. MING CHEN W. YU AND EUGENE GUTH, *University of Notre Dame.*—For the multiple scattering of light or particles by a finite plane-parallel without energy loss, the "spherical harmonic" (S.H.M.) method as developed generally, for solving the Boltzmann integro-differential equation to nth approximation for any anisotropic single scattering law developable into a series of legendre polynomials. To any approximation, the S.H.M. method is proved to give the same formal solution as the "gauss quadrature method" (G.S.M.) as developed by Wick and Chandrasekhar, the only difference being in the boundary conditions. Both the S.H.M. and the G.S.M. are applied to the multiple scattering of electrons by a finite medium. The Goudsmit-Saunderson and Williams theories are shown to be the small angle and Fokker-Planck approximations to the Boltzmann equations neglecting back scattering. We obtain nth approximations not only for the forward but also for the back scattering. The relation of our work to that by Bothe, Rose, Bethe and Smith, Moliere, Snyder-Scott, and Lewis will be discussed.

FRIDAY MORNING AT 9:45

Shoreham, Terrace Room

(J. E. GOLDMAN presiding)

Metals

N1. Theory of Mobility of Grain Boundaries.* R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—Motion of a grain boundary during grain growth can be represented as a process of disordering of a group of n atoms on one side of the grain boundary and an ordering of a similar group of atoms on the other side of the grain boundary in continuation of the crystalline lattice of the growing grain. A simple extension of Mott's theory of viscous slip along grain boundaries allows to include the surface energy of the boundary and to estimate V, the rate of motion of a boundary, when the motion is caused by the curvature of the boundary itself. Using experimental data of various authors on aluminum, silver, and brass, the average number of atoms n is obtained and the constant V_0 in the equation $V = V_0 \exp(-nL/kT)$ is theoretically calculated in agreement with experiment for the three metals. (L is the heat of fusion.)

* Research sponsored by an AEC contract.

N2. Diffusion along Individual Grain Boundaries.* R. SMOLUCHOWSKI AND M. R. ACHTER, *Carnegie Institute of Technology.*—The structure of grain boundaries is still the subject of much speculation. There is, however, little doubt that the structure depends upon the relative orientation of the two grains and of the grain boundary itself. In order to get an insight into these phenomena the diffusion of silver along individual grain boundaries of columnar copper (common direction of one cubic axis of all grains) has been studied. The experiments, conducted at a rather low temperature so as to enhance the grain boundary diffusion as compared to volume diffusion, indicate that grain boundary diffusion is greatest when the angle between the two grains is around 45 degrees. The rate of diffusion drops rapidly with decreasing (or increasing) angle and reaches the rate of volume diffusion at an angle of 20 (or 70) degrees. This result suggests that at small angles the grain boundary can be described as an array of individual parallel dislocations, while at higher angles the dislocations bunch up and the grain boundary is better described in terms of Mott's islands of fit and of misfit.

* Research sponsored by an AEC contract.

N3. Anisotropy of Grain Boundary Diffusion.* M. R. ACHTER AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—It has long been assumed that a metallic grain boundary can be described as a layer of highly disordered atoms in which little, if any, correlation with the crystalline lattice of the two grains exist. However, a closer analysis based either on the dislocation model or on the "island" model indicates that this is over simplification and that the structure of a grain boundary in general has a definite directionality. In order to prove this a study was made of diffusion of silver along individual grain boundaries of copper in two mutually perpendicular directions. It appears that diffusion along grain

boundaries is anisotropic and this anisotropy depends upon the relative orientation of the grains. As a rule, whenever the grain boundary can be represented as an array of parallel edge dislocations, then diffusion is faster in the direction of the dislocations. A similar interpretation is obtainable on the "island" model.

* Research supported by an AEC contract.

N4. Absorption by Beryllium in the Neighborhood of the *K* Edge.* D. H. TOMBOULIAN AND R. W. JOHNSTON, *Cornell University.*—Following the experimental procedure described in a previous report,[1] preliminary measurements have been carried out on the absorption by Be in the spectral range 80 to 300A. The absorbers consisted of metallic foils or layers of Be deposited on Zapon backing films by evaporation. The absorption curve reveals a rather sharp *K* edge located at approximately 110A. Though no previous measurements seem to have been reported on the absorption spectrum of Be, the position of the edge is in agreement with that observed previously[2] in the emission spectrum of Be. The available observations indicate the existence of secondary structures on the short wavelength side of the *K* edge. So far, it has not been possible to arrive at reliable values of the absorption coefficient owing to uncertainties in the nature and in the thickness of the absorbers used.

* Supported in part by the ONR.

[1] E. M. Pell and D. H. Tomboulian, Phys. Rev. **76**, 172 (1949).
[2] H. W. B. Skinner, Trans. Roy. Soc. (London) **239**, 95 (1940).

N5. Spectrographic Study of the Electron Energy Bands in Metals.* R. H. KINGSTON AND E. M. GYORGY.—With the equipment described in the previous paper it has been possible to reproduce with excellent agreement O'Bryan and Skinner's curves for Na, Mg, and Al. As a result of the ability to run consecutive curves on the spectrograph at intervals of five minutes or less, it is possible to observe the slow contamination of the surface of the specimen after the initial evaporation of the material on to the target. Skinner, in unpublished correspondence, has found that the metals Ti through Zn do not show sharp emission edges as would be expected from the electron theory of metals. Tentative data which we have taken on manganese indicate that this is also true even at the low bombarding voltages we have been using. Before further studies to determine whether the broad emission edges in the transition metals are a result of satellite and Auger effects rather than a definite anomaly in electronic structure we are investigating potassium and calcium, since they lie midway between the transition metals and aluminum, which shows a very sharp edge.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and ONR.

N6. A High Vacuum Recording Spectrograph for the Study of Solids in the 50–1000A Range*. E. M. GYORGY AND R. H. KINGSTON.—The two-meter grazing-incidence vacuum spectrograph used by O'Bryan and Skinner[1] for the study of the emission bands of solids has been rebuilt to operate with improved sensitivity and speed. The major modification is the replacement of the photographic plate by a Be-Cu photomultiplier which is designed to traverse the Rowland circle, giving a continuous record of photon-counting rate as a function of a wavelength. With the photo-multiplier it is possible to take as many separate curves as desired, subject to x-ray target condition, without opening the spectrograph, which is normally evacuated to better than 10^{-5} mm Hg. In addition, the sensitivity is increased about a thousandfold; i.e., with a photographic plate the target current and voltage needed are 10–100 ma and about 3000 volts for a one- to three-hour exposure. Using the photo-multiplier, however, we require only 2–3 ma at voltages of 300–500 volts, and the complete emission band may be recorded in a matter of about 5 minutes.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and ONR.

[1] H. M. O'Bryan and H. W. B. Skinner, Phys. Rev. **45**, 370 (1934).

N7. Frequency Dependence of Elastic Constants and Losses in Nickel. W. P. MASON, H. J. MCSKIMIN, AND R. M. BOZORTH, *Bell Telephone Laboratories.*—The elastic constants of nickel crystals,[1] and their variation with magnetic field (ΔE effect), have been measured by a 10-megacycle ultrasonic pulsing method.[2] The constants of three crystals agree well with each other when the crystals are magnetically saturated, but vary with domain distribution when demagnetized. The maximum ΔE effect observed is much less (3 percent) than has been observed at lower frequencies (20 percent). By measuring the ΔE effect and the decrement of polycrystalline rods at low frequencies, it is shown that the small effect observed at 10 megacycles is due to shielding in single domains by micro-eddy currents. From the initial slope of the decrement-frequency curve, and also from the frequency of maximum decrement, the size of the average domain is found to be about 0.03 mm. Actual domains in single nickel crystals have been observed optically by Williams, who finds domain widths of 0.02 to 0.2 mm. Our results then indicate that regions swept by domain walls, displaced by stresses, correspond to whole domains of the original structure.

[1] Bozorth, Mason, and McSkimin, Phys. Rev. **75**, 1954 (1949).
[2] H. J. McSkimin, J. Acoust. Soc. Am. **22**, 413 (1950).

N8. The Thermal Conductivity of Titanium between 20 and 273 Degrees Kelvin. CARL J. RIGNEY, *Southern Illinois University,* AND LESTER I. BOCKSTAHLER, *Northwestern University.*—Measurements were made on cylindrical rods approximately 8 mm in diameter and 72 mm long mounted inside an evacuated hollow copper cylinder. The top of the rod supported a heating coil, while the other end firmly fitted into the base of the copper container which was immersed in a refrigerant. Corrections for radiation and spurious conduction were made by a substitution method. Results for a specimen of commercially pure titanium and a titanium alloy containing 2.8 percent chromium and 1 percent iron are tabulated below. The error for any determination does not exceed five percent except at 20°K, where it is less than ten percent.

Temperature Deg K	Conductivity in watts cm^{-1} C $degrees^{-1}$ Ti	Alloy
273	0.20	0.13
195	0.21	0 10
90	0.18	
80	0.17	0.06
20	0.12	

N9. Periodic Schottky Deviations for Molybdenum and Tungsten. E. A. COOMES, E. G. BROCK, AND A. L. HOUDE, C.S.B., *University of Notre Dame.*—Periodic deviations in the Schottky effect have been studied for the thermionic emission from molybdenum and tungsten filaments. These studies were made both for the clean state obtained by flashing, and for contaminated states obtained by electropositive and electronegative films deposited on the clean filaments. The range of applied fields was 10^3 to 4×10^5 volts cm^{-1}, and the range of temperatures was 1400°K to 1850°K. The positions of maxima and minima as determined experimentally support the mirror image model. Variations of amplitude with temperature were also consistent with this model. Contamination by an electronegative film caused the phase to shift to higher fields, in contrast to the shift to lower fields resulting by an electropositive contamination.

N10. A Collective Description of Particle Interactions. DAVID PINES, *University of Pennsylvania,* AND DAVID BOHM, *Princeton University.*—A new method of treating a dense assembly of strongly interacting particles, which was applied previously to the case of transverse electromagnetic interactions between electrons,[1] has now been extended to the coulomb interactions in a dense electron gas. Instead of solving the individual particle equations of motion, we introduce collective coordinates which are effectively the normal coordi-

nates of the system as a whole. In a suitable approximation, these coordinates, as a result of the coulomb interaction, oscillate harmonically with a determinable characteristic frequency and describe the major part of the charge density. The remainder of the charge density produces a screened coulomb potential for electron-electron interaction with a screening radius which can be expressed in terms of the average particle kinetic energy and the particle density. This collective method can be applied to a general interparticle potential $V(\mathbf{x}_i-\mathbf{x}_j)=\Sigma_k\,(V_k/L^3)\exp i\mathbf{k}\cdot(\mathbf{x}_i-\mathbf{x}_j)$. One can show that for a given wave number, $\mathbf{k}$, the criterion that this method provide a better approximation then a description in terms of the individual particles is $nV_k>2T/3$, where n is the particle density, and T is the mean particle kinetic energy. Thus, strong forces and high particle density favor collective behavior, while high random velocities oppose it. The relation of our method to Tomanaga's one-dimensional treatment[2] will be discussed.

[1] D. Bohm and D. Pines Phys. Rev. (to be published).
[2] S. Tomanaga, Progress of Theoretical Physics.

N11. Application of Collective Description to Electron Interactions in a Metal. DAVID BOHM, *Princeton University*, AND DAVID PINES, *University of Pennsylvania*.—Application of our collective description to electron interactions in a metal requires a quantum mechanical treatment. This has been accomplished by means of a suitable canonical transformation which expresses the individual particle coordinates and momenta in terms of collective coordinates and momenta associated with the normal modes of the system. The hamiltonian then reduces to the sum of three groups of terms; harmonic oscillator terms associated with normal modes, effective kinetic energy terms associated with the individual particles, and a residual term describing screened coulomb electron interactions. For a typical metal, the screening radius is approximately one-third the interparticle distance,[1] so that the mean free path for electron-electron collisions is ten times the interparticle distance. Our analysis thus tends to justify the usual Bloch approximation, which neglects electron interactions. We also predict a phenomenon analogous to Čerenkov radiation; *viz.*, a very fast electron will transfer energy to the normal modes of the metal in integral multiples of the basic quantum of collective oscillation. Experiments tending to verify this prediction will be discussed.[2]

[1] D. Bohm and D. Pines, Phys. Rev. **80**, 903 (1950).
[2] C. Herring (private communication).

N12. The Influence of Electric Field on Electric Current in Metallic Conductor. OLEG YADOFF, *Columbia University*.—It is known that the resistance of metallic conductors set in a magnetic field has increased with the increase of the field intensity. We observed a new phenomenon: influence of electric field on electric current. This action is manifested in a decrease in resistance. If we apply electric concentric field to a conductor through which electric current flows, we have a noticeable decrease in resistance. The demonstrated apparatus consists of a receiving charge wire conductor placed concentrically in a metal tube the wall of which has been connected to a pole of electrostatic generator. The current may be ac or dc the electrostatic pole may be positive or negative. The effect begins to show from 10 kv:cm. Through the action of this field we may increase the current—20 percent more than the normal intensity. The pressure in the test apparatus, as well as the nature of the gases used has certain importance. But in all cases the phenomenon exists and can be perfectly observed. The phenomenon is accompanied by some physical changes. For example, during many experiments we observed that if we introduced some gas, smoke, etc., into the apparatus, the action of this phenomenon was to destroy them.

FRIDAY MORNING, 9:45 to Noon

NBS, East Building

(A. V. ASTIN presiding)

Work of the National Bureau of Standards, Part I

P1. The Current Research Programme of the National Bureau of Standards. A. V. ASTIN. (20 min.)
P2. Atomic Systems as Primary Standards. R. D. HUNTOON.
P3. Penetration and Diffusion of X-Rays and Electrons. U. FANO.
P4. The Spectra of Artificial Elements. W. F. MEGGERS.
P5. Recent Results in Supraconductivity and Superfluidity. J. R. PELLAM.
P6. Physical State of Outer Atmosphere. A. G. MCNISH

FRIDAY AFTERNOON, 2:00 to 4:15

NBS, East Building

(W. R. BRODE presiding)

Work of the National Bureau of Standards, Part II

PA1. Monte Carlo Methods for Calculating Eigenvalues. J. H. CURTISS.
PA2. Application of Electronic Digital Computers to Physical Problems. R. J. SLUTZ.
PA3. Automatic Programmed Computing Machines for Optical Design. I. C. GARDNER.
PA4. Crystal Synthesis. H. F. MCMURDIE.
PA5. The Hot-Wire Technique in Aerodynamic Research. G. B. SCHUBAUER.
PA6. Recent Developments in Acoustics. R. K. COOK.

FRIDAY AFTERNOON AT 2:15

Shoreham, West Ballroom

(J. M. CORK presiding)

Radioactive Nuclei Beyond Cerium

Q1. The Radiations from Hafnium. S. B. BURSON, K. W. BLAIR, H. B. KELLER, AND S. WEXLER, *Argonne National Laboratory.*—Four activities in Hf, induced by neutron bombardment in the Argonne Laboratory reactor, have been investigated by spectrometric and counting techniques. Isotopic assignments were verified by activation experiments on the enriched isotopes obtained from the Oak Ridge National Laboratory. Each decay process was verified by ascertaining which orbital electron work functions yielded the most consistent results when fitted to the internal conversion lines from the gamma-rays associated with an activity. These results are summarized in the table:

Activity	Process	Gamma-ray energies in kev
$_{72}Hf^{181}$ (45 d)	420 kev β^-	611, 481, 344, 136, 133
$_{72}Hf^{180*}$ (5.5 hr)	Isomeric	442, 330, 214, 93.2, 56.8
$_{72}Hf^{179*}$ (19 sec)	Isomeric	161
$_{72}Hf^{175}$ (70 d)	*K*-capture	342, 228, 113, 89.1

The 5.5-hour activity was found to be an isomeric state of $_{72}Hf^{180}$ and thus a violation of the Mattauch Rule for even-even nuclei. Delayed coincidence curves showed that the 420-kev beta-ray of $_{72}Hf^{181}$ leads directly to a 22-microsecond metastable state of $_{73}Ta^{181}$.

Q2. Long-Lived Gamma-Radiation Following Neutron Capture in Iridium. J. M. CORK, J. M. LEBLANC, A. E. STODDARD, W. J. CHILDS, C. E. BRANYAN, AND D. W. MARTIN, *University of Michigan.*—A continued spectrometric study of iridium, irradiated in the high neutron flux of the Argonne pile, shows many electron lines not previously observed. The half-life of Ir^{192} is found to be 78 days and the isotope decays both by beta-emission to Pt^{192} and by *K* capture to Os^{192}. About 45 electron lines are observed including Auger lines for both osmium and platinium. The electron lines having *K-L-M* differences characteristic of platinium yield 9 gamma-rays with energies between 135.9 and 611.2 Kev. These energies fit remarkably well as transitions within a simple nuclear structure of 6 levels. There appear to be 4 gamma-rays in Os^{192} associated with the *K*-capture process. Four single electron lines cannot be uniquely assigned. A single gamma-ray of energy 327.5 Kev is emitted following the beta-decay of Ir^{194} to Pt^{194} with a 19-hour half-life. This project was supported jointly by the ONR and the AEC.

Q3. Angular Correlation of the Gamma-Rays Emitted from the Excited States of Pt^{196}.* R. M. STEFFEN AND D. M. ROBERTS, *Purdue University.*—The nuclide Au^{198} ($T_{\frac{1}{2}}=5.6$ d) decays by *K*-capture into Pt^{196} leading to two excited states of 0.688-Mev and 0.358-Mev energy and also[1] by β^- emission into Hg^{196}. The angular correlation of the two successively emitted gamma-rays following the *K*-capture has been measured, using the apparatus described before.[2] The experimental data are well represented by the correlation function $f(\theta)=1-(15/13)\cdot\cos^2\theta+(16/13)\cdot\cos^4\theta$, which is characteristic for two quadrupole transitions between states of angular momentum 2,2 and 0.[3] The conversion coefficients[1] of the two gamma-rays indicate electric quadrupole transitions suggesting the same parity for all three levels involved. These assignments, however, lead to the difficulty that the cross-over transition should be predominant, whereas the intensity of this transition has been measured to be less than 5 percent. The spin and parity assignments of all the excited levels involved in the dual decay of Au^{198} will be discussed.

* Supported in part by the AEC.
[1] Steffen, Huber, and Humbel, Helv. Phys. Acta **22**, 167 (1949).
[2] R. M. Steffen, Phys. Rev. **80**, 115 (1950).
[3] D. R. Hamilton, Phys. Rev. **58**, 122 (1940).

Q4. The Radiations of Tl^{199} and Tl^{200}.* H. I. ISRAEL, T. L. HARLOR, AND R. G. WILKINSON, *Indiana University.*—The gamma-rays of Tl^{199} and Tl^{200} produced by alpha-particle bombardment of gold have been investigated in a 180°-shaped field spectrometer. The photo-electrons and internal conversion electrons were studied with carrier-free sources prepared by electrodeposition from a solution containing the chemically separated radiothallium. The activities associated with the 7-hour Tl^{199} and the 27-hour Tl^{200} were easily differentiated by following the decay rates. In the case of Tl^{199}, conversion lines at 50, 60, 70, 120, 140, 160, 190, 220, 240, 310, and 450 kev were observed. These can be considered to be associated with gamma-rays from Hg^{199} with energies of 70, 150, 200, 230, 320, and 540 kev. These values are in good agreement with those reported[1] in a study of the decay of Au^{199} to Hg^{199}. In the disintegration of Tl^{200}, photo-electrons and internal conversion electrons were observed which can be ascribed to gamma-rays of Hg^{200} with energies of 0.36, 0.57, 0.83, and 1.2 Mev. Coincidence studies by Cuffey in this laboratory show that at least two of the gamma-rays are in cascade. A decay scheme consistent with the measured energies and the coincidence-absorption data will be proposed. No positrons were found in either case.

* This work was supported by the joint program of the ONR and AEC.
[1] Beach, Peacock, and Wilkinson, Phys. Rev. **76**, 1585 (1949).

Q5. An Alpha-Gamma Angular Correlation in the Decay of Radiothorium.* J. K. BELING, B. T. FELD, AND I. HALPERN, *M.I.T.*—The angular correlation between the short-range alpha-particles and the gamma-rays of ~85 kev emitted in the decay of radiothorium has been measured. Both radiations were detected with scintillation counters. The gamma-phosphor was a NaI(Tl) crystal, ½ inch thick, and the alpha-detector was a flake of anthracene 0.01 inch thick. Data were taken for the first ten hours after chemical separation of RdTh from its decay products, and differential discrimination was employed on both alpha- and gamma-pulses. The observed correlation is roughly $1+\sin^2 2\theta$, in disagreement with an earlier measurement.[1] Recent experiments[2] indicate that the decay involves gamma-rays of energies 83.3 and 86.8 kev which do not occur in cascade and that the 83.3-kev radiation is three times more intense than the 86.8 kev. These energies have not as yet been resolved in this experiment but the average energy has been confirmed. Provided that two gamma-rays of comparable intensity are not emitted successively, the correlation can be ascribed to a principal mode of decay having spins 0-2-0 for the sequence $RdTh \xrightarrow{\alpha} ThX^* \xrightarrow{\gamma} ThX$. The possibility of cascade emission is being investigated.

* Assisted by the joint program of the ONR and AEC.
[1] Kul'chitski, Latyshev, and Bulyginski, Bull. Acad. Sci. URSS, Sér. Phys. **13**, 331 (1949).
[2] M. Riou, J. phys. radium **11**, 185 (1950).

Q6. Disintegration of Np^{239}. R. L. GRAHAM AND R. E. BELL, *Chalk River Laboratory.*—The radiations of Np^{239} have been studied by millimicrosecond coincidence techniques in two thin lens beta-ray spectrometers placed end to end. Np^{239} emits a complex beta-ray spectrum with end points at 705±15

kev (7 percent), 435±15 kev (46 percent), and 310±20 kev (47 percent), and conversion lines due to gamma-transitions of 49, 57, 61, 67, 210, 227, and 276 kev. Delayed-coincidence measurements showed that the 210-, 227-, and 276-kev transitions follow a state of half-life $(1.1\pm0.1)\times10^{-9}$ second. Coincidence studies on focused conversion lines showed that the 227- and 276-kev transitions are not in cascade, and that the 67- and 210-kev transitions are in cascade. Fermi plots of coincidences between nuclear beta-rays and the 210-, 227-, and 276-kev transitions all have end points at 435 kev. No radiations were found coinciding with the 705-kev beta-spectrum, which thus leads to the ground state of Pu^{239}. The 435-kev spectrum goes to a 276-kev level of half-life $(1.1\pm0.1)\times10^{-9}$ second, which is de-excited by the gamma-transitions 276 kev, or (227 and 49) kev or (210 and 67) kev. The 310-kev beta-spectrum goes to a level at about 394 kev. The information found here agrees generally but not in detail with the disintegration scheme of Kohman.[1]

[1] Nuclear Data, Nat. Bur. Standards Circular No. 499 (1950).

Q7. Conversion Lines and Beta-Spectra of Np^{239}. E. P. TOMLINSON, H. W. FULBRIGHT, AND J. J. HOWLAND, JR., *Princeton University and Brookhaven National Laboratory.*—The momentum distribution of electrons emitted by Np^{239} has been studied using a 20-cm radius high resolution double focusing magnetic spectrometer of the Siegbahn-Svartholm type. Eighty-eight electron lines were observed with varying degrees of certainty down to an energy of 3 kev. Most of these lines were obtained with a full width at half-maximum in Np between 0.3 and 0.4 percent. About two-thirds of the lines are accountable as conversion electrons from 11 gamma-rays. A Kurie analysis of the underlying beta-spectra gives clearly at least four beta-groups and possibly other lower energy groups. Preliminary values, in kev, for the gamma-ray energies are 286, 277, 254, 228, 209, 105, 67.5, 61.4, 57.0, 49.0, 44.2. Preliminary values for the beta-ray end points, in Mev, are 0.715, 0.654, 0.44, 0.33. The energy level scheme of Pu^{239} will be discussed on the basis of these data. The work was supported in part by the joint program of the ONR and AEC.

Q8. Radiation Spectra from Short-Lived Nuclides.* D. J. ZAFFARANO AND F. I. BOLEY,† *Iowa State College.*—Spectra have been obtained from nuclides with half-lives larger than 0.1 second made by x-rays from the Iowa State College synchrotron. A short pneumatic tube is used to transfer the sample to a scintillation spectrometer which employs photographic pulse height registration on a moving film to record the data. Calibration is effected with Cl^{34} (4.45 Mev) and Y^{90} (2.24 Mev) sources. Fermi plots of S^{31} (3.2 sec),[1] Cl^{33} (~2.4 sec),[2] and Ca^{39} (1.06 sec) indicate maximum positron energies of 3.74±0.2, 3.70±0.2, and a preliminary value of 4.2 Mev, respectively. These belong to the group of radioactive nuclei having one fewer neutron than proton.[1,2] Their relationship to the other members of the group will be discussed.

* This work was performed in the Ames Laboratory of the AEC.
† Socony-Vacuum Research Fellow.
[1] Scheiberg, Sampson, and Mitchell, Rev. Sci. Instr. 19, 458 (1948).
[2] White, Creutz, Delsasso, and Wilson, Phys. Rev. 59, 63 (1941).

Q9. Measurement of γ-Ray Energies with a Scintillation Spectrometer.* E. DER MATEOSIAN, *Brookhaven National Laboratory.*—A scintillation spectrometer especially useful for the study of energies of short-lived γ-ray emitters has been developed. The light output from a NaI-Tl activated crystal is recorded with the help of a DuMont oscilloscope and a Polaroid camera. Some of the results of interest are the following. The β-emitter Ti^{51} (6 min) shows the same γ-rays as the K-capturer Cr^{51} (26 d). In both cases a 320-kev state of V^{51} is excited. Mo^{101} (14.5 min) and its daughter Tc^{101} (15 min), which had both been reported[1] to have a γ-ray of 300 kev, are found instead to possess γ-rays of 150 kev and 260 kev, respectively. Nb^{94m} (6.6 min), for which a weak γ-ray of 1.3 Mev[1] had been reported (probably following a weak β-branch) is found instead to have a γ-ray of 0.9 Mev.

* Research carried out under contract with AEC.
[1] See K. Way, *et al.*, Nuclear Data, Nat. Bur. Standards Circular 499.

Q10. A Type of Correlation of the Half-Lives of β^- Emitters for Odd Isotopic Numbers. D. N. KUNDU AND M. L. POOL, *Ohio State University.*—For nuclei on the neutron excess side of the valley of stability, the logarithm of the half-life t of β^- emitters of odd A is approximately a linear function of Z for a constant value of $I=A-2Z$. Both odd and even Z have been examined for values of I from 1 to 25. In some cases the linearity holds through a range of 1 to 10^{10} in half-lives. From this linear relationship $\log t=\alpha Z+\delta$, it follows that within this range, $|M|^2f=Ae^{-\alpha Z}$, where $|M|$ is the nuclear matrix and f the usual integral Fermi function. The constant α has approximately the same value 0.59 for all values of I. This may be compared with $\alpha=0.35$ obtained previously for β^+ emitters in a similar study. The interpretation is that the slope of instability is steeper on the β^+ side than the β^- side of the valley. The curves help predict the half-lives of probable isotopes for given Z and I. Though, in general, both $|M|^2$ and f may individually be complicated functions of Z, the product $|M|^2f$ has simple exponential charge dependence for about 65 percent of known β^- emitters of Seaborg classification A.

Q11. The Assay of Radioactive Water by a Methane Proportional Counting Method. CHARLES V. ROBINSON, *New England General Hospital.*—In a suitable vacuum system, radioactive water can be combined with methyl Grignard reagent to give radioactive methane which can be collected in a counting chamber by partial trapping with liquid nitrogen. Subsequent operation of the chamber as a proportional counter gives a measure of the specific activity of the water.[1] A method of assay based on these principles is being used for routine measurements in surgical studies employing tritium as a water tracer.[2] The method gives s standard deviation less than 1 percent on repeated measurements, shows no significant "memory effect" from one sample to the next, and is relatively convenient for a gas phase method. Some details of the apparatus and technique will be described.

[1] The preliminary work on this method is to be published: C. V. Robinson, Rev. Sci. Instr.
[2] Under Public Health Service Grant.

FRIDAY AFTERNOON AT 2:00

Wardman Park, Continental Room

(H. A. BETHE presiding)

General Theory

QA1. Representation of Nucleon-Nucleon Singlet Scattering. G. BREIT AND M. C. YOVITS,* *Yale University.***—This paper is concerned with the calculation of the f function which depends on phase shift K and energy E only. It is constant for potentials having zero range, varies linearly with E for short range potentials, and determines $K(E)$ conveniently in a wide

energy range. The calculation of the power series in E representing f for a given potential is shown to be possible by means of the expansion

$$[f-f^{(0)}]/(E/e^2)=\sum_0^\infty \int_0^\infty [(u_p{}^s)^2-u_p{}^2]dr$$

$$+\sum_0^\infty \int_0^\infty [u_p{}^s u_{p+1}{}^s-u_p u_{p+1}]dr,$$

where $f^{(0)}$ is the energy independent term, p is an integer, and u_p is the term containing E^p in the power series expansion of u in E; u is $C_0\mathfrak{F}/\sin K$ in standard notation. The function u^s is the comparison function for zero range force; u^s is varied with E to fit f. The functions u_p were first used by Jackson and Blatt to obtain terms in E^2 and E^3. The series shown contains E^{2p} in the term in $u_p{}^2$ and E^{2p+1} in the term in $u_p u_{p+1}$. An analogous expansion in a linear parameter multiplying a part of the potential energy has a similar structure. Applications will be discussed.

* AEC Predoctoral Fellow.
** Assisted by the joint program of the ONR and AEC.

QA2. Relativistic Symmetry in the Basic Formulation of Quantum Theory. O. COSTA DE BEAUREGARD, *Institut Henri Poincaré, Paris.*—The spinning-particle-in-a-field theory has been given relativistic symmetry. A *state* is identified when one knows ψ on a space-like surface $\mathcal{S}$; the *evolution* of ψ is given by the associated cauchy problem. The definition of hermitian scalar products is generalized, so as to be given on $\mathcal{S}$; nevertheless, conserving its fundamental properties, which allow the construction of a hilbert space. As the operator of the total energy, the hamiltonian is replaced by $\hbar\partial/i\partial t$; the stochastic distribution related to $\mathcal{S}$ of the four operator $\hbar\partial^k/i$ is described by its so-called *characteristic function*, introduced into quantum theory by E. Arnous, through Stone's and Bochner's theorems.[1] Formulas are given for the variation between two $\mathcal{S}$'s of the *characteristic* and *distribution* functions of $\hbar\partial^k/i$, the latter leading to Feynman's rules in his well-known *positron theory*. Our theory proceeds entirely from two Notes of October 1947 in the *Comptes Rendus*, where we suggested the interpretation of the positron subsequently developed by Feynman; it is being presented in a series of Notes in the *Comptes Rendus* (1950–1951).

[1] Stone and Bochner, J. phys. radium **8**, 87–93 (1947).

QA3. Invariance of Two-Body Interactions Under Space and Time Inversion. R. A. FERRELL,* *Princeton University.*—We will indicate the unsuitability of the usual inversion operators and replace them with operators defined differently, giving two examples. These operators for a quantum mechanical system are a matter of convention; but in the classical limit, the expectation values of the velocities, v_i, must differ in sign for corresponding inverted states. The conventional inversion operators are not acceptable, for they reverse the momenta, p_i, instead of v_i. Equivalently expressed, the convention is not gauge invariant. We replace the conventional operator O by O', determined from (A) $O'v_iO'^{-1}=-v_i$. This gives $O'=UO$, with U unitary. With hamiltonian $H=\Sigma_i \times p_i{}^2/2m_i+\Sigma_i a_i p_i+\Sigma_i b_i p_i+V$, where a_i, b_i, V independent of p_i, $Oa_iO^{-1}=a_i$, $Ob_iO^{-1}=-b_i$, and (B) $\partial a_i/\partial x_j=\partial a_j/\partial x_i$, all i, j, one finds $U=\exp -2i/\hbar\int \Sigma_i m_i a_i dx_i$. If (B) *invalid*, no O' satisfies (A); and *for a given state, a corresponding inverted state with the required properties does not exist.* When (B) valid, O' is gauge invariant, and linear terms of $O'HO'^{-1}$ and H agree. Choosing gauge so $a_i=0$, $O'=O$, and $\Sigma_i a_i p_i$ reduces to static terms. Example I: electron in uniform magnetic field. There is a space O' but no time O'. Example II: many velocity dependent *two-body interactions*, termed non-invariant by Wigner and Eisenbud,[1] are now actually inversion invariant but equivalent to static forces. Therefore, their list of invariant forces remains unaffected.

* AEC Predoctoral Fellow.
[1] Wigner and Eisenbud, Proc. Nat. Acad. Sci. U. S. **27**, 281 (1941).

QA4. A Unified Field Theory with Varying Charge and Mass. H. C. CORBEN, *Carnegie Institute of Technology.**—Field equations and geodesic equations of motion for a point particle are derived from a unified field theory in five dimensions, the extra metric elements being given by $g_{i5}=\alpha A_i$, $g_{55}=1+\alpha^2\Phi$, α being a constant independent of the particle, A_i the electromagnetic potentials, and Φ a scalar field. The charge e and mass m of the particle are introduced as $e=M\alpha(dx^5/d\tau)$, $m=M(ds/d\tau)$, with $d\tau^2=g_{\mu\nu}dx^\mu dx^\nu$, $ds^2=g_{ij}dx^i dx^j$ $(\mu,\ \nu=1\cdots5,\ i,\ j=1\cdots4)$, M being a constant characteristic of the particle. The geodesic equations then yield a modified Lorentz force equation in which e and m are not necessarily constants of the motion, even if $\Phi=0$ and there is no gravitational field ($g_{ij}=0$ $(1\neq j)$, $g_{11}=g_{22}=g_{33}=-1$, $g_{44}=1$). Even a neutral particle in the presence of one that is charged has a charge induced on it, the total charge on the two being constant only if $\Box\Phi=0$ in the linear approximation. The effect is negligible for two particles of equal mass at relative rest if $r\gg m\alpha^2$. The mass of a neutral particle exceeds that of a charged particle characterized by the same M by an amount, which corresponds to the neutron-proton mass difference, if $\alpha=e_0/\mu$, where e_0 is the free proton charge, and $\mu=95$ times the mass of the electron. In the linear approximation, the field equations become, for no gravitational field, $\Box A_i=-j_i$, $\partial_i A_i=\psi$, $\partial_\nu A_i=0$, $\partial_i\psi=0$, with $\Phi=(2\pi^\frac{1}{2}\psi/\alpha)$ $(c=1)$, j_i being proportional to T_{i5}, where $T_{\mu\nu}$ is an energy momentum current tensor describing the fields other than A_i, ψ which may be present.

* Supported by ONR contract.

QA5. Parameters and Constraints in Quantized Field Theories.* PETER G. BERGMANN, *Syracuse University.*—Covariant field theories can be brought into a canonical formulation either with or without the introduction of so-called parameters. In the latter method, the four space-time coordinates become automatically q-numbers, and their canonical conjugates are the energy and linear momentum densities.[1] The algebraic constraints in a parametrized theory are four more than in the other formalism. It will be shown that both in the classical and in the quantized theory, parametrization is a reversible procedure in the sense that the appearance of additional q-numbers is more apparent than real and can be reversed by an appropriate unitary transformation. Work in progress at present intends to examine the effect that singularities of the field may have.

* Supported by ONR.
[1] P. G. Bergmann and J. H. M. Brunings, Revs. Modern Phys. **21**, 480 (1949).

QA6. On the Range of Application of the Lagrange and Hamilton Formalisms. PETER HAVAS, *Lehigh University.*—Lagrange's and Hamilton's formalism are usually regarded as encompassing only forces, Q_i, which are either derivable from a potential or for which a function U can be found such that $Q_i=d/dt(\partial U/\partial\dot{q}_i)-\partial U/\partial q_i$ (e.g., the Lorentz force). The general conditions under which the equations of motion are the euler-lagrange equations of a variational principle have been investigated by several authors,* and a rather stringent set of conditions was established. It was, however, apparently overlooked that there are cases in which these conditions are not fulfilled originally, but can be satisfied by multiplying the equations of motion by a suitable "integrating factor." In particular, the one-dimensional equations of motion under arbitrary velocity-dependent forces are always derivable from a variational principle. The hamiltonian can be obtained from the lagrangian as usual. If the forces do not depend explicitly

on the time, it is still a constant of motion, although it is not the energy. Cases of motion in more than one dimension, which can be brought under this scheme, and the problem of quantization will also be discussed.

* A. Hirsch, Math. Ann. 50, 429 (1898) and references given there.

QA7. On the Second Quantized Dirac Theory of Spin ½ Particles. R. K. OSBORN, *Case Institute of Technology*.—The second-quantized Dirac hamiltonian for free electrons is transformed by a canonical transformation to a representation in which the positive and negative energy wave operators are separately represented by two component operators. The transformation employed is the second-quantized analog of the one derived by Foldy and Wouthuysen[1] in their discussion of the one-particle dirac theory and its non-relativistic limit. This transformation is then applied to the wave operators and the hamiltonian in the second-quantized, charge-conjugate formalism for Dirac particles. The wave operators for positrons and electrons become linearly-independent two-component operators, and the hamiltonian separates into an electron and a positron part, each of which contains only the corresponding two-component wave operators. It is shown that the independent wave operators for electrons and positrons anticommute. Work is in progress to investigate the interactions between spin ½ particles and the electromagnetic and meson fields in this representation.

[1] L. L. Foldy and S. A. Wouthuysen, Phys. Rev. 78, 29 (1950).

QA8. Multiple Quantization. A. E. SCHEIDEGGER, *Queen's University*.—An inspection of the canonical quantization procedure shows that it is essentially an algebraic one. The time-dependent generalized coordinates q_k, which are classically subject to the lagrangian differential equations, are reinterpreted as (time-dependent) hermitian operators in a hilbert space. Thus, it is seen that quantization leads from a time-dependent hilbert vector (the q_k's) to another time-dependent hilbert vector, which suggests that it is a "circular" process, and may be repeated. The ordinary Schrodinger equation, however, is not suitable for further quantization, since reality is essential for a quantizable hilbert vector. Also, the Schrodinger equation contains only first-order time derivatives, the analogous lagrangian equations, however, contain second-order ones. Both facts can be taken care of by constructing differential equations for the real and imaginary parts of the Schrödinger function. These equations are then analogous to the lagrangian equations from which the quantization was started. They form the closing link in the quantization as a "circular" process. This method is applied to obtain the third quantization of the Schrödinger-Gordon equation. Speculations that an infinitely multiple quantization of classical equations may yield the true description of nature, are suggested.

QA9. Gauge-Independent Quantum Electrodynamics. F. J. BELINFANTE AND J. S. LOMONT, *Purdue University*.—Pauli's gauge-independent quantum electrodynamics (*Handbuch der Physik*) not quantizing longitudinal fields, earlier generalized to include positon theory, has been reformulated in interaction representation. The interaction operator W depends on the complete surface σ on which it operates. We defined W for flat surfaces only, as $(\mathbf{E}_{\perp}{}^2/8\pi)+(\mathbf{E}_{\parallel}.\mathcal{E}/4\pi)-\mathbf{j}.\mathcal{A}$ in a Lorentz frame in which σ is t=constant. Here, $\{\mathcal{E}, \mathcal{B}\}$ is the quantized field tensor for transverse photons in interaction representation; the current density four-vector $\{\rho, \mathbf{j}\}$ is expressible in terms of spinors $\bar{\psi}$ and ψ; $\mathcal{A}(x)\equiv\int d^3x'\ \mathrm{curl}'\mathcal{B}(x')/4\pi r$ and $\mathbf{E}_{\parallel}(x)\equiv-\nabla V(x)\equiv-\nabla\int d^3x'\rho(x')/r$ are given functionals of the gauge-independent field variables on σ. The integrability of the generalized Schrödinger equation for translations and rotations of σ (time dependence and Lorentz transformation of $\Psi[\sigma]$) is proved. In Heisenberg representation, ψ is no longer a spinor, and not $\{\mathcal{E}, \mathcal{B}\}$ but $\{\mathbf{E}, \mathcal{B}\}$ forms a tensor, where $\mathbf{E}=\mathcal{E}+\mathbf{E}_{\parallel}$, thence $\mathcal{E}=\mathbf{E}_{\perp}$. Omission of self-energy from $(\mathbf{E}_{\parallel}{}^2/8\pi)$ disturbs integrability and Lorentz invariance of the Schrödinger equation, unless one simultaneously postulates, as in integro-causal quantum field theory, the unallowability of self-interaction through virtual photons from $(\mathbf{E}_{\parallel}.\mathcal{E}/4\pi)-\mathbf{j}.\mathcal{A}$.

QA10. On Coherent Scattering Processes in Liquids. LOUIS GOLDSTEIN, *Los Alamos Scientific Laboratory*.—The coherent scattering structure factor of liquids for x-rays and slow neutrons will be shown to determine completely both the correlation function and the direct local interaction function of liquids, quantities of which are the only operating elements of the general static liquid models of Ornstein and Zernike. Of these functions only the former has been derived, so far, from the data accumulated essentially on the coherent scattering of x-rays by liquids. It will be shown that the directly available experimental structure factors completely determine the even moments of these molecular distribution functions. The zeroth moment of the correlation function augmented by unity is essentially the liquid concentration fluctuation which determines its isothermal compressibility. These quantities thus become directly derivable from the structure factor measurements without any arbitrary and uncertain manipulations. In terms of the liquid model, a straightforward method leads to the total incoherent slow neutron scattering cross sections in liquids. These should yield important information on their energy spectrum not available through other types of scattering processes, such as x-rays, for instance.

QA11. Phase Space Description for the Multiple Scattering of Waves. WILLIAM L. LEHMANN AND MELVIN LAX, *Syracuse University*.—The solution of a wave problem leads to a wave function $\psi(r; r_1, r_2, \cdots r_n)$ describing the amplitude of radiation at r due to scatterers at $r_1, r_2, \cdots r_n$. One prefers, however, to obtain the answer in terms of the density and directionality of the radiation *versus* position, i.e., in terms of the density of radiation in phase space. The space density of the radiation is, in fact, described by $\langle|\psi(r; r_1, \cdots r_n)|^2\rangle$, where an average is taken over an ensemble of scatterer positions. A simultaneous description of the density of the radiation in ordinary space and momentum space may not seem to be possible because of the Heisenberg uncertainty principle. There is, in fact, no *unique* phase space description. Following a suggestion of Wigner's,[1] it is possible, however, to introduce a phase space density $F(k, r)$: $F(k, r)=(2\pi)^{-3}\int\exp[ik\cdot\rho]d\rho\langle\psi^*(r+\frac{1}{2}\rho)\psi(r-\frac{1}{2}\rho)\rangle$. An integral equation, found previously by one of us, for $\langle\psi^*(r')\psi(r)\rangle$ can now be transformed into an integral equation for $F(k, r)$. The significance of the latter integral equation will be discussed.

[1] E. P. Wigner, Phys. Rev. 40, 749 (1932). See also J. E. Moyal, Proc. Cambridge Phil. Soc. 45, 1, 99 (1949).

QA12. Spin-Spin Interaction in the Spectrum of FeIII. R. E. TREES, *University of Pennsylvania*.—The term intervals of one quintet and seven triplets of the d^5 configuration of FeIII[1] have been analyzed in an effort to detect effects of spin-spin interaction. The mean deviation of the experimentally given intervals from the Lande interval rule was 44 cm^{-1}. Correction for non-diagonal spin-orbit elements reduced this to 9 cm^{-1}. The value of the Lande radial parameter was $\zeta_d=429\pm16$. The elements of spin-spin interaction were calculated for d^5 configurations, using methods of G. Racah. The spin-spin interactions are determined by two radial parameters, M_0 and M_2, defined by Marvin.[2] These were found by least squares, using the deviations from the Lande rule not accounted for by non-diagonal spin-orbit interactions as the data to be fitted, to have the values $M_0=0.304$ and $M_2=0.018$. The correction for spin-spin interaction reduced the residual deviation of 9 cm^{-1} to 4 cm^{-1}. It is concluded that spin-spin

interactions have an appreciable, though small, effect on the term intervals in this spectrum.

[1] B. Edlen and P. Swings, Astrophys. J. 95, 532 (1942).
[2] H. H. Marvin, Phys. Rev. 71, 102 (1947).

QA13. An Equivalence of Classical and Quantum Mechanical Treatments of Radiation. M. H. HULL, JR., *Yale University.**—It is well known that the results of quantum-electrodynamics are in close agreement with a classical model employing radiation oscillators. The results of Wigner and Weisskopf have been generalized by Breit, who showed that for dipole radiation and for photons with energies within the natural line breadth the similarity of results can be explained in terms of the possibility of identifying suitable multiples of classical dynamical variables (amplitude of transition oscillator, amplitudes of radiation oscillators) with quantum probability amplitudes (those for the atomic excited state and for the excitation of radiation oscillators). In the present paper, this correspondence is extended to cases including retardation effects and multipole radiation. It is shown that the equivalent classical current systems can always be set up.

* Assisted by the joint program of the ONR and AEC.

QA14. Heat Conduction In Simple Metals.* MARTIN L. STORM,** *New York University.*—The partial differential equation of heat conduction is a non-linear equation when the temperature dependence of the thermal parameters (i.e., the thermal conductivity K, and S, the product of the density and the specific heat at constant pressure) is taken into account. It is shown that a mathematical condition for the transformation to linear form of the one-dimensional, non-linear, partial differential equation of heat conduction is the constancy of $[1/(KS)^{\frac{1}{2}}]d/dT \log(S/K)^{\frac{1}{2}}$. This discovery is the motivation for an investigation of the relations between the thermal parameters of simple metals on the bases of the theory of solids and available experimental data. It is found that KS is essentially constant, its variation with temperature being much less than that of either K or S considered separately. It is also shown as a result that the condition for the above-mentioned transformation is valid for simple metals. Applications of the transformed equation to the solution of problems in heat conduction are considered.

* Work supported by the ONR and the Office of Air Research.
** Now at the Naval Ordnance Laboratory, White Oak, Maryland.

FRIDAY AFTERNOON AT 2:00

Shoreham, Terrace Room

(K. LARK-HOROVITZ presiding)

Crystals and Semiconductors

R1. New Methods of Phase Determination in X-Ray Crystal Analysis.* RAY PEPINSKY AND WILLIAM COCHRAN,† *The Pennsylvania State College.*—Two new methods of phase determination in x-ray analysis have been explored on X-RAC. Both make use of knowledge of the known bounds and expected shape of a density function. Method I involves the use of Cesaro means, temperature-corrected fourier coefficients, or other techniques for reducing the number of coefficients involved in a synthesis. The characteristics of Fejer's and Poisson's kernels, and the kernel $(1+\cos x)^n$, are discussed in this connection. Method II involves a modification of an unpublished method of D. Sayre, already successfully applied by him. Sayre's method utilizes the properties of the squared density-function, and the relations of this to the original function. It can be strengthened, by considering $F(h,k)/f(h,k) = \hat{F}(h,k)$'s as fourier coefficients of a *partial* sharpened-up density function ρ_n, formed from a few of the largest $\hat{F}(h,k)$'s. The condition that ρ_n must have positive regions which go much higher than the negative can be imposed by requiring $\int \rho_n{}^3 dA$ = maximum positive. When the number of terms is small, this requires $s(h,k) = s(h^1,k^1)s(h+h^1,k+k^1)$, where $s(h,k)$ indicates the sign of $F(h,k)$. The method has been applied successfully to the determination of the previously-unknown structure of glutamine.

* Development supported by ONR.
† Rockefeller Foundation Fellow.

R2. Lithium-Ammonium Tartrate, a New Ferroelectricum. WALTER J. MERZ,* *The Pennsylvania State College.*—We have found that $LiNH_4C_4H_4O_6 \cdot H_2O$ becomes ferroelectric at low temperatures and has a Curie point at about 106°K (−167°C). Although this crystal is strongly related crystallographically and chemically to rochelle salt ($KNaC_4H_4O_6 \cdot 4H_2O$), we observe the following principal differences. The ferroelectric direction is along the b axis, whereas in rochelle salt it is along the a axis. There is just one molecule of water of crystallization instead of the four which were considered as a main feature in rochelle salt. The Curie point is much lower (for rochelle salt θ is at room temperature). We measured the dielectric constants in all 3 directions. They all show a value of only about 9 at room temperature. ϵ_a and ϵ_c stay about constant when the temperature is lowered, whereas ϵ_b has a sharp peak at $\theta = 106$°K. The crystal also shows the typical minimum in the resonance frequency at θ, since it becomes very soft. Hysteresis loops show, quite in analogy to other ferroelectrics, the onset of a spontaneous polarization at θ and an increase in this polarization when the temperature is lowered. We are now also investigating other crystals of the same alkali tartrate group.

* Investigation supported by Office of Air Research.

R3. Neutron Diffraction Studies on Vitreous Silica.* W. O. MILLIGAN, *The Rice Institute,* H. A. LEVY, AND S. W. PETERSON, *Oak Ridge National Laboratory.*—Neutron diffraction patterns of transparent vitreous silica plates have been obtained at wavelengths of 1.21A (sodium chloride monochromator) and 0.764A (single copper crystal monochromator). A neutron crystal spectrometer similar in design to that of Wollan and Shull was employed. Six well-defined diffraction maxima were observed, in contrast to a single broad peak and three ill-defined peaks observed by Warren with x-rays; but, in general, agreement with the several diffraction peaks reported by Melkonian and Ruderman from neutron velocity selector transmission studies. The intensities were corrected for absorption and were converted to absolute intensities, using diffraction peaks from nickel powder. Data from both wavelengths agree closely, except at low angles near the incident beam. The scattering curve is similar to that of Webber for soda-lime glass. A radial distribution curve has been calculated for vitreous silica, using the method of Warren. Integrations were carried out with an IBM calculator. The radial distribution curve shows five well-resolved peaks at

distances of about 1.58, 2.56, 3.02, 4.0, and 5.1A. Less well-defined peaks were observed at 5.9, 6.6, 7.4, 9.0, and 9.7A. The positions and areas of the peaks are in close agreement with the results of Warren and co-workers. The detection of additional peaks and the observed higher resolution suggest that neutron diffraction studies offer advantages over x-ray studies for the examination of amorphous and colloidal materials. The greater usefulness of neutrons is attributed primarily to the angular independence of neutron scattering cross sections.

* Work done in part under the research participation program of the Oak Ridge Institute of Nuclear Studies for the AEC.

R4. Directional Breakdown Effects in Ionic Crystals.* ELMER L. OFFENBACHER AND HERBERT B. CALLEN, *University of Pennsylvania.*—Although the breakdown strength of ionic crystals is independent of crystal orientation, the breakdown paths proceed in definite crystallographic directions which are determined by the temperature. Von Hippel has suggested a breakdown mechanism, involving slow electrons, which is able to predict breakdown strengths fairly satisfactorily. As a resolution of the directional paradox he has also suggested that the breakdown paths depend upon the behavior of fast electrons. We have accordingly attempted to develop a specific mechanism leading to the appropriate directional sensitivity of fast electrons. The directional asymmetry of the Brillouin zone of the phonons and the selection rules for electron-phonon collisions caused the total collision probability to depend on electron direction, and the electron tends to migrate in the direction of smallest scattering probability. We have computed the differences in collision probability for various directions and find that the 111, 110, and 100 directions are each preferred in specific energy ranges. Plausible criteria for the selection of the dominant direction at a given temperature lead to rough agreement with the observations of J. W. Davisson, which, however, are insufficient to provide a decisive test of theory.

* Supported in part by ONR.

R5. The Absorption Spectra of Pure and Colored Alkali Halide Crystals.* D. L. DEXTER,† *University of Wisconsin.*—The absorption cross section per electron is calculated for ultraviolet radiation in NaCl at the first exciton band, at the exciton series limit, at the *F*-band, and at the *F*-center series limit. The *F*-center wave functions used are similar to those determined by Tibbs.[1] The exciton wave function is taken to be that of an electron bound to a stationary positive hole, multiplied by the lattice function of Tibbs.[1] The continuum wave functions used are hydrogenlike continuum wave functions spread out by the dielectric constant of the crystal. The calculated cross sections are in agreement with experiment within a factor of about 2. This agreement tends to verify Mott's suggestion that the small hump or plateau seen at about 0.6 ev above the *F*-band in some absorption data[2] represents the series limit of transitions of the *F*-center electron. Qualitative extension of these results will be made to other crystals.

* Research supported in part by ONR.
† Now at the University of Illinois.
[1] S. R. Tibbs, Trans. Faraday Soc. **35**, 1471 (1939).
[2] F. G. Kleinschrod, Ann. Physik **27**, 97 (1936).

R6. Electromotive Force in Illuminated Alkali Halide Crystals Caused by a Gradient in the Color Center Density. GERHART GROETZINGER AND SAM BARILE, *Lewis Laboratory, NACA.*—Color centers with a density gradient were produced in thirty NaCl and KBr crystals in two ways: (1) Crystals of approximate dimensions of 1×1×0.5 cm were exposed for 15 minutes to x-rays produced by a beryllium window tube operated at 50 kv and 30 ma, the x-rays entering through one of the square faces. (2) Crystals were colored by the pointed cathode method and subsequently cut to the above-mentioned dimensions in a way that [as in (1)] a gradient essentially in the direction of the small dimension was obtained. Emf's in the crystals in the direction of the gradient produced by uniform illumination with white light (tungsten ribbon filament lamp) were determined in the following way: using a vibrating reed electrometer effectively shunted by a 10^9-ohm resistor as a null-indicator, the voltage between two Aquadag electrodes on the square faces was measured by compensation. Potential differences of about one-tenth of a volt were thus observed, the more densely colored part of the crystal being positive. The emf's are indicative of a difference in concentration and/or mobility of conduction electrons and holes.

R7. Study of X-Ray Induced Optical Absorption Bands in CaF_2. SAM BARILE, *Lewis Laboratory, NACA* (Introduced by G. GROETZINGER).—The absorption spectrum of CaF_2 crystals containing color centers was investigated as a function of temperature and time elapsed after having been irradiated with x-rays under various conditions. Crystals, 0.5 cm thick, were exposed to x-rays from a beryllium window tube operated at 50 kv and 30 ma for as much as 20 hr. Under these conditions saturation of the color center density is reached. Absorption measurements were made with a Beckman spectrophotometer in the range between 2100 and 10,000A. A fourth weak absorption band previously unobserved has been found near 2280A. The intensities of the four absorption bands of crystals irradiated at room temperature decreased (within experimental error) to the same extent after being heated at various temperatures for various time intervals. Furthermore, no difference in the relative intensities of the bands was found between crystals irradiated at room temperature and elevated temperatures (200°F).

R8. A Theory of the λ-Point Transition in Ammonium Chloride. N. K. POPE, *Chalk River Laboratory.*—The potential energy of an ammonium ion due to its angular displacement from an equilibrium position is expanded in a series of spherical top wave functions. Those terms in the potential energy which depend on the angular displacements of other ammonium ions are replaced by their average values. The number of terms in the potential energy is greatly reduced by applying symmetry conditions for the ammonium ion and for the lattice. The first angle dependent term in the potential energy has T_d^1 symmetry; the second has O_h^3 symmetry; the third term has higher symmetry and tends to bind the ammonium ion to the equilibrium orientation which is common to the first two terms. It is shown classically that such a potential function gives rise to a transition which corresponds to a sudden increase in the angular motion of the ammonium ions. This result is consistent with the neutron diffraction measurements by G. H. Goldschmidt and D. G. Hurst[1] on ND_4Cl.

[1] G. H. Goldschmidt and D. G. Hurst, Paper HA11, Bull. Am. Phys. Soc. **26**, No. 1, 58 (1951).

R9. Electrical Properties of Titanium Dioxide Semiconductors. R. G. BRECKENRIDGE AND W. R. HOSLER, *National Bureau of Standards.*—Measurements have been made of the Hall effect and resistivity of titanium dioxide that had been made semiconducting by reduction in hydrogen for various times and temperatures. The samples included ceramics and rutile single crystals oriented in both the *a* and *c* directions. The temperature range covered was from −190°C to 500°C. The results of the Hall effect measurements indicate that the charge carriers are electrons. The number of electrons in these strongly reduced materials approaches a constant value of the order of 10^{17} to 10^{18}/cm³ at low temperatures and increases by a factor of *ca* 10^2 as the temperature is raised to 500°C. The resistivity of the samples varies slowly with temperature over the same range, usually passing through a broad maxima. No major differences were noted between the densely

fired ceramics and the single crystal samples in either orientation, although the electron mobility in the crystals is somewhat smaller in the a than in the c direction. The observed mobilities in all cases were low.

R10. Effect of Impurity Content on the Specific Heat of Germanium.* I. ESTERMANN AND J. R. WEERTMAN, *Carnegie Institute of Technology.*—It has been reported[1] that the specific heat of Ge has an anomaly at 80°K. Since Ge forms a monatomic lattice of the diamond type, it was difficult to associate the excess specific heat with any known lattice process. Preliminary measurements of the specific heat curve of Ge carried out by one of us in 1944 on a pure Ge sample failed to show the reported anomaly. New measurements with much higher precision were carried out with a very pure and a less pure sample of 10^{20} impurity centers per cm³. The results show that the excess of specific heat of the impure over the pure sample is no more than the order of one percent. No anomaly of the type reported by Simon and Critescu was found.

* Assisted by the ONR and the Research Corporation.
[1] S. Critescu and F. Simon, Z. physik. Chem. (B)25, 273–282 (1934).

R11. The Photo-Voltaic Effect of Survace $P-N$ Barriers in Germanium. B. J. ROTHLEIN, *Sylvania Electric Products, Inc.*—Surface barriers on germanium can be made having an exceptionally high photo-voltaic response. These barriers can be used as a cell possessing high signal to noise ratio owing to their use at zero current. The shape of the spectral response curve at room temperature is similar to what has previously been reported for germanium;[1] the decay in response with increased chopping frequency, however, appears somewhat greater. The characteristics of this effect will be described.

[1] M. Becker and H. Y. Fan, Phys. Rev. 78, 301 (1950).

R12. Germanium Rectifier Characteristics. R. N. HALL, *General Electric Research Laboratory.*—Rectifiers made from purified germanium wafers whose opposite faces are strongly doped with donor and acceptor impurities have electrical characteristics which follow a simple theoretical formula over a current range extending from the saturation reverse current to several hundred amperes per cm² in the forward direction in the temperature range between 200° and 400°K. Since the region in which holes and electrons recombine is the well-defined volume between the impurity layers, the calculation of the diode current is not difficult and is given by

$$I=(q\ln/\tau)[\exp(qv/2kT)-1].$$

The high purity region has a thickness l, while n and τ are the concentration and lifetime of the carriers in intrinsic germanium. The factor of ½ in the exponential results from the use of a volume recombination rate which is essentially linear in the concentrations of holes and electrons. The rectifier characteristics indicate that the direct recombination of holes and electrons, which varies as the product of their concentrations, becomes appreciable only at very high forward currents. The experiments give a volume recombination time for the linear process of 0.0002 sec at room temperature, while the lifetime for direct recombination is of the order of 0.03 sec.

R13. Motion of Vacancies in a One-Dimensional Homogeneous Lattice. YÜ-CHANG HSIEH* AND I. BLOCH, *Vanderbilt University.*—An atom in a perfect crystal is assumed to be in a stationary one-dimensional potential well. When one of its neighbors is removed, the atom finds itself in a wider well with a "hump" in the middle; its wave function then becomes a wave packet which moves back and forth between the two lattice sites. The motion of this wave packet is related to the coefficient of diffusion of "holes" in the lattice, and hence to the coefficient of self-diffusion of the substance composing the lattice. This crude model indicates that even at low temperatures "holes" diffuse rather rapidly, because of the tunnel effect.

* Now at Purdue University, Lafayette, Indiana.

R14. Photo-Conductivity of Trapped Electrons in the Alkali Halides. J. J. OBERLY, *Naval Research Laboratory.*—The photo-conductivity of the color center bands (F, R, M, N, S) associated with trapped electrons in alkali halide crystals has already been reported.[1] Quantitative measurements have now been made at room temperature on crystals irradiated with soft x-rays to obtain the relative photo-current per absorbed photon for the various types of centers. This relative response is proportional to the quantum yields if the ranges (Schubwege) of the electrons freed from the various centers are the same. In KBr all of the bands are found to be photo-conductive after their formation by x-rays or by optical bleaching of other bands. However, both the F- and M-bands can be made relatively non-photo-conductive by bleaching them with F- and M-light, respectively. The "soft" fractions of the bands which bleach readily are the photo-conductive portions, while the residual "hard" absorption is caused by non-photo-conductive centers. The peak absorption wavelength of the hard F centers is slightly shorter, corresponding to the B-band of Petroff. The hard type of center has not been observed for the other bands which is an indication of the similarity of the F- and M-bands on one hand and of the R- and N-bands on the other.

[1] J. J. Oberly and E. Burstein, Phys. Rev. 79, 217 (1950).

FRIDAY AFTERNOON AT 2:15

Shoreham, Main Ballroom

(A. O. NIER presiding)

Nuclear Masses, Abundances, and Magnetic Moments

RA1. Atomic Masses in the Region About Mass 40. T. L. COLLINS, ALFRED O. NIER, AND WALTER H. JOHNSON, JR., *University of Minnesota.*—The double-focusing mass spectrometer already described[1] has been used to measure masses of isotopes near $M=40$ by the doublet method, comparisons being made with hydrocarbons. H^1 and C^{12} were taken as 1.008165±4 and 12.003842±6, respectively.[2] The isotopes measured and the packing fractions ($\times 10^4$, all negative) computed were as follows: S^{32}, 5.41; S^{34}, 6.24; Cl^{35}, 5.71; Cl^{37}, 6.03; A^{36}, 5.83; A^{38}, 6.59; K^{39}, 6.12; K^{41}, 6.10; Ca^{42}, 6.60; Ca^{43}, 6.36; Ca^{44}, 6.99; Ca^{45}, 6.72; Sc^{45}, 6.62. The probable errors varied between 0.01 and 0.02. Fluctuations from nuclide to nuclide follow approximately those predicted by the Bohr-Wheeler formula except about Ca^{40} and Ca^{48}, where the nuclides are actually somewhat more stable than the formula predicts. The discrepancy is especially marked for Ca^{48}.

[1] A. O. Nier and T. R. Roberts, Phys. Rev. 81, 507 (1951).
[2] A. O. Nier ,Phys. Rev. 81, 624 (1951).

RA2. Masses of Th^{233} and U^{233}. GEORGE S. STANFORD AND HENRY E. DUCKWORTH, *Wesleyan University.**—The mass spectrograph has been used to photograph doublets at mass number 58 consisting of singly-charged Fe^{58} and quadruply-charged Th^{232}, at mass number 116 consisting of singly-charged Sn^{116} and doubly-charged Th^{232}, and at mass number 119 consisting of singly-charged Sn^{119} and doubly-charged U^{238}. The following packing fraction differences were measured: $Th^{232}-Fe^{58}$, $\Delta f=13.17\pm0.06$: $Th^{232}-Sn^{116}$, $\Delta f=9.89\pm0.03$: and $U^{238}-Sn^{119}$, $f=10.24\pm0.03$. Using the known packing fractions[1] of Fe^{58}, Sn^{116}, and Sn^{119} of -8.43 ± 0.07, -5.30 ± 0.05, and -4.79 ± 0.05, respectively, the packing fraction of Th^{232} is found to 4.64 ± 0.10 from the Th−Fe comparison, 4.59 ± 0.06 from the Th−Sn comparison, and that of U^{238} is found to be 5.45 ± 0.06. The corresponding masses are $Th^{232}=232.1070\pm0.0012$ and $U^{238}=238.1297\pm0.0015$. Some remarks will be made concerning the agreement between these mass values and that[2] of $Pb^{208}=208.0422\pm0.0015$ on the basis of radioactive decay data.

* Supported by the AEC.
[1] To be published.
[2] H. E. Duckworth and R. S. Preston, Phys. Rev. (to be published).

RA3. Masses of Xe^{129} and Xe^{132}. CORT L. KEGLEY AND HENRY E. DUCKWORTH, *Wesleyan University.**—The mass spectrograph has been used to photograph a triplet at mass number 43 consisting of singly-charged C_3OH_3 and C_4H_7 and triply-charged Xe^{129}, and a second triplet at mass number 44, consisting of singly-charged CO_2 and C_3OH_4 and triply-charged Xe^{132}. The following packing fraction differences were measured: $C_4H_7-Xe^{129}$, $\Delta f=20.15\pm0.02$; $C_3OH_3-Xe^{129}$, $\Delta f=11.68\pm0.025$; $C_3OH_4-Xe^{132}$, $\Delta f=13.08\pm0.025$; CO_2-Xe^{132}, $\Delta f=4.90\pm0.02$. Using the masses[1] $H^1=1.008147$ and $C^{12}=12.003794$, the packing fractions of Xe^{129} and Xe^{132} are computed to be -4.23 ± 0.02 and -3.99 ± 0.05, respectively, corresponding to the masses $Xe^{129}=128.94543\pm0.00026$ and $Xe^{132}=131.94733\pm0.00066$. It is hoped that masses will also be reported for Kr^{89}, Kr^{84}, and Kr^{86}. Typical mass spectra will be shown.

* Supported by the AEC.
[1] K. T. Bainbridge (private communication).

RA4. Nuclear Reaction Energies and Nuclear Masses as Integral Multiples of a Natural Unit of Mass and Energy. ENOS E. WITMER, *University of Pennsylvania.*—About a year ago the writer pointed out that one-eleventh of the rest mass of the negative electron appeared to be a natural unit of mass and energy for nuclei and elementary particles not subject to β-decay. This unit of mass and energy was designated *the prout*. Furthermore, it was pointed out that the neutron and many other nuclei subject to β-decay appeared to follow the integral rule. Recently, "Energy levels[1] of light nuclei, III" appeared, giving a more accurate and extensive set of values for nuclear reaction energies. These data as well as other recent data support the hypothesis stated above very well. These results are self-consistent, so that it is possible to make a table of nuclear masses in prouts up to about Ne^{20}. Because of the slight uncertainty in M_p/m this has been done both with 20196 prouts and 20197 prouts as the proton mass. In the second case the nuclear masses in prouts are A prouts larger. But the *nuclear masses in mass units* differ only in the sixth or seventh decimal places in the two cases, since O^{16} is standard.

[1] Hornyak, Lauristen, Morrison, and Fowler, Revs. Modern Phys. 22, 291 (1950).

RA5. A New Method for the Measurement of the Isotopic Abundance of Solids. H. SOMMER AND J. A. HIPPLE, *National Bureau of Standards.*—Several measurements of isotopic abundance have been made on a modified Dempster mass spectrometer to demonstrate a method of using electrical detection with a high frequency vacuum spark source. The use of electrical detection is made possible by measuring the ratio of the selected ion current to a representative sample of the total ion current produced by the spark source. Although the emission from the source fluctuates erratically owing to the nature of the spark, the observed ratio remains essentially constant. The successful use of this instrument for quantitative analysis of solids has been previously described.[1] Tentative results of the measurement of the isotopic abundance of nickel, copper, and magnesium yield values with accuracies comparable to other recently published results. For example, the value obtained for the isotopic abundance of copper in atom percent is: $Cu^{63}=68.94\pm0.26$; $Cu^{65}=31.06$. The results obtained for magnesium agree closely with those of Hibbs and Redmond.[2]

[1] Gorman, Jones, and Hipple, to be published in Anal. Chem.
[2] R. F. Hibbs and J. W. Redmond, Carbon and Carbon Chemicals Corporation Report Y-290, November 24, 1948.

RA6. Hyperfine Structure of Te^{123} and Te^{125}. JOHN S. ROSS AND KIYOSHI MURAKAWA, *University of Wisconsin.**—Hyperfine structure spectrograms obtained with a liquid-air cooled hollow-cathode source using enriched isotopes show that the Te^{125} I line $\lambda2530.7(5p^4\ {}^3P_1-5p^36s\ {}^5S_2)$ consists of two components 0.113 cm^{-1} apart, the shorter frequency being the stronger. Thus, the magnetic moment of Te^{123} is negative, since Te^{125} and Te^{123} are known to have spin $\frac{1}{2}$. The line $\lambda2385.7(5p^4\ {}^3P_1-5p^36s\ {}^3S_1)$ was found to be single to an accuracy of 0.03 cm^{-1}. Using these data and appropriate hyperfine structure formulas,[1] the value $\mu(Te^{125})=-0.74\pm0.20$ n.m. was obtained. From the large splitting of the Te II lines $\lambda5449$ and $\lambda5311$ the ratio μ^{125}/μ^{123} was found to be $1.188\pm.010$, which gives the result $\mu(Te^{123})=-0.62\pm0.20$ n.m. This indicates that both nuclei are probably in an $S_{\frac{1}{2}}$ state, which is in agreement with the prediction of Mayer's nuclear shell theory.

* Supported by the ONR.
[1] M. F. Crawford and L. A. Wills, Phys. Rev. 48, 69 (1935).

RA7. Hyperfine Structure of Tungsten.* JOHN A. VREELAND AND KIYOSHI MURAKAWA, *University of Wisconsin.*—The hyperfine structure of the tungsten spectrum was examined with a Fabry-Perot etalon, using two samples enriched in W^{180} and W^{182}, respectively. The structure of W^{183} in more than twenty-five arc lines was measured, and the splittings of more than twenty terms determined. The value of the magnetic moment of W^{183} was found to be $+0.08\pm0.02$ n.m. The isotopic displacement effect in the arc lines gave $\Delta(W^{186}-W^{184}):\Delta(W^{184}-W^{182}):\Delta(W^{183}-W^{180})=1.00:1.13\ (\pm0.01):1.02\ (\pm0.02)$.

* Supported by the ONR.

FRIDAY AFTERNOON AT 2:15

NBS, Materials Testing

(W. J. LYONS presiding)

High-Polymer Physics and Biophysics

S1. Apparatus for Determining the Dielectric Behavior of Liquids, Gels, and Solids at Audiofrequencies. EDWIN R. FITZGERALD* AND ROBERT F. MILLER, *B. F. Goodrich Company Research Center.*—Apparatus has been developed for determining the dielectric behavior of liquids, gels, and solids of the type encountered in plasticized polymer systems over the entire range of plasticizer concentration. A combination dielectric cell with plane, parallel electrodes and a guard ring, suitable for use from 15 to 15,000 cps at temperatures from −100 to +150°C has been constructed and used in measurements on plasticized polyvinyl chloride and other systems. Included also is the variation of dielectric constant and loss factor with frequency and temperature for dimethyl thianthrene, tricresyl phosphate, di-2-ethyl hexyl phthalate, a polyvinyl chloride—dimethyl thianthrene gel (90 percent dimethyl thianthrene by volume), and a butadiene-acrylonitrile copolymer. Activation energies of dipole rotation are found to be 46.0 kcal/mole (−4 to −20°C) for dimethyl thianthrene, 41.8 kcal/mole (−31 to −44°C) for tricresyl phosphate, and 24.2 kcal/mole (−51 to −71°C) for di-2-ethyl hexyl phthalate. These compare with activation energies of viscous flow of 46 kcal/mole (at −3°C) for dimethyl thianthrene and 25 kcal/mole (at −44°C) for di-2-ethyl hexyl phthalate determined from falling ball and rotating cylinder viscosity measurements. The agreement between activation energies of viscous flow and dipole rotation is thus marked; but it must be pointed out that the activation energies for viscous flow decrease with rising temperature, while there was no observed change in activation energies of dipole rotation over the narrow temperature ranges in which they were determined.

* Now Physics Department, University of Wisconsin.

S2. A Rheometer for Measuring Dynamic Viscosities and Rigidities.* H. MARKOVITZ, P. M. YAVORSKY, R. C. HARPER, JR., L. J. ZAPAS, AND T. W. DEWITT, *Mellon Institute.*—The design of this instrument as used for liquids is similar to that of the coaxially cylindrical elastometer of Goldberg and Sandvik,[1] but differs from theirs in that it can also be adapted to solids and in that its use is not limited to resonant frequencies. The rheometer has a mechanical drive which can cause oscillations at the fixed angular amplitude of 1° and at frequencies from 1 to 100 cycles per second. The amplitude and phase difference of the response are obtained from the electrical signals produced by coils attached to the moving elements and oscillating between the poles of permanent magnets. Measurements can be made from −60°C to 100°C. With newtonian liquids the behavior of the instrument is in good agreement with that predicted by theory. Measurements with non-newtonian liquids indicate that amplitude of vibration here is low enough so that the results are independent of rate of shear. Results obtained with solid polymers are similar to those reported for like materials by other techniques.

* Work supported by the Office of Rubber Reserve, Reconstruction Finance Corporation, Washington, D. C.
[1] H. Goldberg and O. Sandvik, Anal. Chem. 19, 123 (1947).

S3. A Stress-Temperature Study of Polyethylene. S. LEONARD DART, *American Viscose Corporation.*—A series of samples was prepared by relaxing a highly stretched polyethylene monofilament various amounts. This series was then used in a stress-strain-temperature-length study. With increasing relaxation, the linear thermal expansion coefficient changed from a large negative value to a large positive maximum and then decreased to a stable value. A stress-strain breakdown of this series shows a large negative entropy force at low stretches changing to a large positive one at high stretches. The internal energy force generally shows a behavior inverse to this. A comparison is made between the entropy force as measured by the stress-temperature method and that calculated from the linear thermal expansion coefficient and the Young's modulus. A plot of the initial Young's modulus of each member of the series against extension shows good agreement with kinetic theory and yields an "internal pressure" of about 1000 atmospheres.

S4. Combined Thermal and Primary Ionization Effects on a Bacterial Virus.* W. R. ADAMS AND ERNEST POLLARD, *Yale University.*—Since a primary ionization causes a sharp localized rise in temperature, it is possible that at least part of the biological action of primary ionization is of the nature of local thermal action. If this viewpoint is correct, there should exist a definite relationship between temperature effects and radiation effects. To test this, dry *T*-1 bacteriophage was used because of its relative stability at temperatures of 100°C. The results show that when *T*-1 bacterial virus is bombarded by deuterons or x-rays at temperatures well above room temperature, the inactivation proceeds definitely faster. On the other hand, when the virus is bombarded by x-rays at −73°, there is no significant change in the rate of inactivation. It is thus seen that although there is a relationship between the two processes, this relationship is not such as to permit explanation of radiation effects as purely thermal. The interpretation of these results is not obvious, but it may be suggested that the effect of heat is to lower the energy requirement for radiation action and thus increase the radius of action of an ionization under the thermally altered conditions.

* Assisted by the AEC.

S5. Inactivation of Penicillin by Deuteron Bombardment.* MARGUERITE DAVIS AND ERNEST POLLARD, *Yale University.*—The bombardment of large enzyme molecules by deuterons has shown that the presence of a primary ionization anywhere in a large fraction of the molecule causes inactivation. This effect of primary ionization can therefore be used as a test of molecular organization. To check whether some large scale process such as heat is responsible rather than primary ionization, a small molecule, of low temperature stability, namely, penicillin, was bombarded by deuterons in the usual way. The results show that penicillin is very stable to deuteron bombardment and the inactivation curve corresponds to the requirement that one primary ionization be produced in a volume of 700A^3, which is to be compared with the figure 360A^3 expected from the molecular weight. Therefore, the fact that penicillin is organized in small molecules is shown by this technique.

* Assisted by the AEC.

S6. Inactivation of Enzymes by Soft X-Rays. W. R. GUILD,* *Yale University.*—The low voltage x-ray tube described previously[1] has been used to inactivate enzymes in order to determine relative cross sections which can be compared with the results obtained with deuteron bombardment.[2] Since the x-ray

tube delivers to the order of 10^8 roentgens per minute to a thin film of protein, the enzymes can be inactivated in reasonably short time, of the order of 30 minutes for 37 percent survival. So far catalase, urease, and chymotrypsin have been inactivated, with urease having the largest cross section and chymotrypsin the smallest. Further results will be reported.

* AEC Predoctoral Fellow.
[1] Bull. Am. Phys. Soc. **26**, No. 1, abstract D7 (1951).
[2] E. C. Pollard, Am. Scientist **39**, 99 (1951).

S7. Behavior of Hemoglobin Under Irradiation.* R. K. Appleyard, *Yale University.*—The investigation of dog carboxyhemoglobin irradiated by fast charged particles has been continued.[1] The low ion-density part of the cross section *vs* ion density curve has been examined, and preliminary experiments have been carried out on the correlation of antigenic enzymatic and spectroscopic assays of the material. The splitting of the heme-globin linkage by irradiation has been further investigated.

* Assisted by the AEC.
[1] Bull. Am. Phys. Soc. **26**, No. 1, 15 (1951).

S8. Electron Bombardment of Enzymes and Viruses.* M. Slater, *Yale University.*—Equipment has been constructed so that the 0.1-μamp beam of 1.5-Mev electrons, available from the Yale linear electron accelerator under present low power operation, can be used for bombarding the viruses and enzymes previously studied[1] by deuteron, ultraviolet, x-ray, and heat inactivation. Measurements of differential energy loss, using two magnetic spectrometers, are being taken. These are compared to theoretical values and yield, with the inactivation data, target volumes. When combined with the deuteron data, this gives the slope-at-the-origin of the cross section *vs* ionization-density curves, and indication of target shapes.

* Assisted by the ONR and AEC.
[1] Pollard, Setlow, *et al.*, Bull. Am. Phys. Soc. **26**, No. 1, 15 (1951).

S9. The Use of Indicator Particles in Ultracentrifugation. H. T. Epstein and Max A. Lauffer, *University of Pittsburgh.*—In many instances, the size and shape of colloidal particles cannot be determined because the particles cannot be obtained sufficiently purified and concentrated to be detected by the usual methods: schlieren, light-scattering, electron microscopy, etc. An ultracentrifuge technique has been developed which allows the determination of the sedimentation constant of the particles to a fair accuracy, provided only that their presence can be detected by some means (physical, chemical, or biological). An indicator particle of known sedimentation constant is added in high enough concentration to be visible as a boundary in the usual schlieren system. The solution is then sedimented in a separation cell until the indicator particle boundary has just reached the barrier. Analysis of the contents of the inner compartment for presence or absence of the colloidal particles then allows the sedimentation constant of the indicator particles to be established as either an upper or a lower limit to the sedimentation constant of the colloidal particles. By using a set of indicator particles with different sedimentation constants, both upper and lower limits can be established for the sedimentation constant of the colloidal particles.

S10. On the Localization of Positron Emitting Isotopes in the Human Body.* Myron L. Good and Frank R. Wrenn, Jr., *Duke University.*—The application of the intrinsic directional properties of the annihilation quanta to the problem of localizing radioactive sources in the human (or animal) body has been explored experimentally. Two NaI—Tl scintillation counters in coincidence detect the arrival of annihilation quantum pairs arising from a positron source; in the absence of scattering, a coincidence counting rate signifies the presence of the source on a straight line joining the two detectors. No collimators are necessary. If scattering is severe, collimators may be employed, their effects being essentially to eliminate the counting of radiation scattered in the body. The method is capable, in principle, of precision limited only by the positron ranges, or the $\approx 1/137$ radian spread of the annihilation quanta. The proposed application of the method to the detection and localization of brain tumors will be discussed. Data taken with a source embedded in a dummy human head will be presented to show the effects of source size, scattering, and diffuse radioactive background. Comparisons with a single collimated scintillation counter will be presented.

* Supported by the AEC.

S11. Relation of the Energy Flux of 22.5-Mev Betatron X-Rays to Ionization Measurements. J. S. Laughlin and J. W. Beattie, *University of Illinois, Chicago.*—The absolute intensity of a carbon filtered 22.5-Mev peak betatron x-ray beam has been calorimetrically determined. A thermistor embedded in a lead cylinder which was exposed to the x-ray beam was employed as a temperature sensitive arm of a wheatstone bridge. Construction of the calorimeter and irradiated cylinders will be described. A heating coil embedded in the cylinder was employed for calibration. The ionization produced in a cavity ionization chamber of known volume immersed in water was measured with the same x-ray beam. The relation obtained was 4580 ± 95 ergs/cm^3—esu/cc, where the esu/cc was measured at equilibrium depth in water. This is equivalent to an absorption of 98 ergs/gram—esu/cc of water. In terms of the reading of the 25-r Victoreen thimble chamber centered in an 8-cm Lucite cube, the flux measured was 4895 ± 100 ergs/cm^2—roentgen (Victoreen). Calibration of other methods of measuring the roentgen will be described.

Friday Evening at 7:00

Shoreham Hotel

(C. C. Lauritsen presiding)

Banquet of the American Physical Society

(Title to be announced): A. T. Waterman, *Director-Nominate, National Science Foundation*

(Title to be announced): E. U. Condon, *Director, National Bureau of Standards.*

SATURDAY MORNING AT 9:45

Shoreham, Terrace Room

(R. R. WILSON presiding)

Apparatus of Nuclear Physics; Bremsstrahlung

SA1. 170-Inch Synchrocyclotron at the University of Chicago. H. L. ANDERSON AND JOHN MARSHALL, *University of Chicago.*—A 170-inch synchrocyclotron has been under construction at the University of Chicago for 3½ years. It is designed to accelerate protons to 450 Mev and deuterons and alpha-particles to 260 Mev and 520 Mev, respectively. Initial operation was achieved on February 16 with the acceleration of deuterons to a radius of 77 inches and a magnetic field of 17600 gauss, which corresponds to the design energy. The average energy of the beam striking a target is certainly somewhat less because of radial oscillations whose amplitude is still unknown. At a repetition rate of 50 cycles per second, the beam strikes a target for approximately one millisecond, i.e., a duty cycle of 5 percent. Measurements of neutron intensity in the beam from a copper target indicate a deuteron current of about 0.1 microampere. Any further progress will be reported.

SA2. Design of the Stanford Billion-Volt Linear Electron Accelerator.* M. CHODOROW, A. ELDREDGE, E. L. GINZTON, W. W. HANSEN,† J. H. JASBERG, C. B. JONES, R. L. KYHL, R. B. NEAL, AND P. A. PEARSON, *Stanford University.*—The principles of a traveling-wave linear electron accelerator have been described.[1] A design has been made for a machine which should be capable of reaching a billion volts. Trial models are in operation at 6 Mev and at 30 Mev. The high intensity traveling electromagnetic wave which provides the accelerating field is at a frequency of 3000 Mc/sec. It is generated by high power klystron amplifier tubes developed for this purpose. There is one klystron for each ten feet of accelerator tube. The electrons are to be accelerated in 1.0 microsecond pulses with a repetition rate of 60 pulses per second.

* Assisted by the joint program of the ONR and AEC.
† Posthumously.
[1] Ginzton, Hansen, and Kennedy, Rev. Sci. Instr. **19**, 89 (1948).

SA3. Progress in Construction and Operation of the Stanford Billion-Volt Linear Electron Accelerator.* P. A. PEARSON, R. B. NEAL, R. L. KYHL, C. B. JONES, J. H. JASBERG, W. W. HANSEN, E. L. GINZTON, A. ELDREDGE, AND M. CHODOROW, *Stanford University.*—Eighty feet of accelerator tube and associated power sources have been constructed. Fifty feet have been operated, driven by five klystrons, each delivering about 10 megawatts peak power. 135-Mev electrons have been obtained in 0.1-microsecond pulses with an average current of 3×10^{-10} amp or about 3×10^{9} electrons per pulse. A spot focus is obtained despite the lack of orbit stability. There seems to be no difficulty in extending the length of the accelerator; and construction is continuing.

* Assisted by the joint program of the ONR and AEC.

SA4. Multiple Cavity Accelerator of Electrons.* B. L. MILLER AND W. C. PORTER, *Bartol Research Foundation.*—An accelerator comprising 5 resonant cavities operated on the divided output of a 10 cm (nominally 1 megawatt) magnetron has produced electron beams up to 1.4 Mev. The energy spectrum has been measured at different power levels, and it is found that approximately 50 percent of the output is bunched around the peak energy in all cases. Absorption curves in aluminum and other materials confirm the peak energy; the linearity of the aluminum curve is indicative of the energy homogeneous bunch. By detuning one or more of the cavities and using variable total power, the peak on the energy spectrum curves can be moved over the region 0.1 to 1.4 Mev. With the present gun injecting 1.0 microamperes at 13 kilovolts, the total current output is 0.1 microampere, which represents a transmission of 10 percent. An earlier 3-cavity model producing 0.7-Mev electrons had been adjusted to give 54 percent transmission. The first cavity is a buncher cavity which increases the total current by a factor of 2, fast component by 4; for the earlier model, the corresponding figures were 3.5 and 5.

* Assisted by the joint program of the ONR and AEC.

SA5. Motion of an Ion in a Fixed Frequency Cyclotron. BERNARD L. COHEN, *Oak Ridge National Laboratory.*—*Horizontal motion:* A study is made of (1) the phase shift per gap crossing, (2) energy gain per gap crossing, and (3) radius as a function of energy. Mathematical expressions are obtained for contributions to (1) from magnetic field change, relativistic mass increase, "grouping" (a tendency to get into phase with the electric frequency), and electric field fall-off; and to (2) from electric field shape and acceleration across the gap. Equations for $r/\delta r$ and $[\dot{\theta}-(eH/mc)\dot{\theta}]$ are involved in (3) (these quantities are shown to perform strongly damped oscillations about zero). Combining (1), (2), and (3) allows calculation of the phase as a function of radius, and the results are shown in terms of the range of electric frequencies which will give transmission, as a function of dee voltage and cyclotron parameters. *Vertical motion:* Modifications of the focusing formulas found in the literature are presented. The complete vertical motion is computed; the displacement is characterized by an exponentially increasing portion which determines the fraction of the ion source current received in the high energy beam. *General:* Formulas are derived for the maximum energy obtainable in a fixed frequency cyclotron as a function of dee voltage, and for the minimum voltage required to obtain a given energy as a function of magnetic field shape.

SA6. Design and Operation Features of an R.F. Ion Source. C. D. MOAK, H. REESE, AND W. M. GOOD, *Oak Ridge National Laboratory.*—Following the general design described by Thoneman, Moffatt, Roaf, and Sanders,[1] an rf ion source has been developed which delivers over 1 ma of positive ions, 90 percent of which are protons. Modifications to Thoneman's source both increase the output current and simplify fabrication of the source to the close tolerance required for large currents. Performance data D_2, He, A, and Xe will be given.

[1] Thoneman, Moffatt, Roaf, and Sanders, Proc. Phys. Soc. (London) **61**, 483 (1948).

SA7. Electron Capture in Betatron Orbits. E. C. GREGG, JR., *Case Institute of Technology.*—Through the instigation of a note by Wideroe, studies were made of the capture conditions in the Case betatron by magnetic perturbation with pulses ranging from 1 to 20μs and variable in amplitude. Such perturbations were tried in slope, field, and flux with no observable difference in effects. It was found that electrons were accepted only at the peak or on the trailing edge of the injection voltage pulse ($dV/dt\leq0$) and that the capture time is about 1μs. Further, the expected parabolic relationship between time and voltage was found to hold at capture. Attempts to capture for $dV/dt>0$ resulted in no output. Additional studies corroborated that capture efficiency rises with

injection current and then saturates. Deliberate azimuthal inhomogeneities were found to increase capture time (up to 4.5μs) but to reduce the total captured charge considerably. The above observations were repeated for various electron injection angles and the conditions for capture found to be the same as above. It appears that constancy or diminution of space charge ($dV/dt \leq 0$) is essential to capture and provides a coupling coefficient for resonant damping.

SA8. Van de Graaff Accelerator for 5.5-Mev Protons. D. M. ROBINSON, L. R. MCINTOSH, AND J. C. NYGARD, *High Voltage Engineering Corporation.*—Reliable operation at 5.5 million volts has been consistently obtained with a van de Graaff proton accelerator in recently completed performance tests. By using differential-pumping and acceleration tubes, having polished aluminum electrodes, whose internal diameter is tapered to the waist part way up the tube, and by pumping with mercury through optically-blocked dry-ice traps, the troublesome electron loading which has heretofore limited maximum voltage is pushed out of the working range of the tubes. The electrostatic generator is housed in a vertical steel pressure tank 8 feet in diameter and 23 feet high. At 5.5 Mev, the magnetically analyzed proton beam intensity is 6 microamperes with an energy homogeneity of ± 0.07 percent, after being deflected through 105 degrees. This stability is obtained with a corona load controlled by the Mass-II beam position. A comparable performance is obtained throughout the energy range 1–5.5 Mev. Although the tank was designed for 400 psi, optimum generator performance has been obtained at 250 psi, using a mixture of nitrogen and carbon dioxide. The above data were obtained without the use of an intermediate equipotential shell. Preliminary results with this shell point toward a small improvement in maximum voltage.

SA9. The Use of Radioactive Material for the Generation of High Voltages. E. G. LINDER AND S. M. CHRISTIAN, *Radio Corporation of America.*—An investigation has been made of the use of beta-emissive radioisotopes for generating high voltages. The voltage was obtained by supporting the beta-emitter on an insulated electrode in a vacuum and allowing it to charge itself by virtue of its electron emission. This method represents a direct conversion of nuclear energy into electrical energy. The apparatus and some associated problems will be described. The characteristics of such a generator will be discussed. Experimental results will be given. Using an emitter containing 0.25 curie of strontium 90, a voltage of 365 kilovolts was obtained.

SA10. High Current X-Ray Tube.* C. H. SHAW AND JACK A. SOULES, *Ohio State University.*—Production of long wavelength x-rays requires the application of relatively low voltage to the x-ray tube if considerable intensity of second-order radiation is to be avoided. To maintain the intensity at a satisfactory level the tube current should be increased accordingly, but in practice, a practical limitation owing to space charge is encountered. A focused beam oxide cathode developed by O. Heil[1] has been adapted to the production of long wavelength x-rays. The cathode is capable of about 500 ma emission at 2500 volts with an electron beam cross section of 3 mm². The beam spreads rapidly upon emergence, unless other provisions are made. A magnetic lens has been used to refocus the beam onto a conventional x-ray target approximately 15 cm from the cathode. Preliminary operation has yielded 180 ma emission current at 1500 volts cathode potential with 135 ma to the target in a focal spot 2 mm diameter. An auxiliary accelerating potential up to 8 kv has been used.

* This work supported by the ONR.
[1] Heil and Ebers, Proc. I. R. E. 38, 645 (1950).

SA11. 65-Mev Bremsstrahlung Spectrum.* RICHARD H. STOKES, *Iowa State College.*—The energy spectrum of the I.S.C. synchrotron x-radiation has been measured by observing the momentum distribution of pair electrons in a cloud chamber. The x-radiation produced in a 5-mil tungsten target was collimated and entered a 12-inch cloud chamber through a beryllium window. A single burst of radiation timed with respect to the cloud chamber expansion produced electron pairs in the air filling of the chamber. The pairs were deflected in a 2500 gauss field and photographed. Preliminary results show reasonable agreement with the Bethe-Heitler theory. Also, a value will be obtained for the number of quanta per unit solid angle at the center of the beam in the range 5–65 Mev, as correlated with readings of a Victoreen thimble chamber surrounded by lead ½-inch thick.

* Work was performed in the Ames Laboratory of the AEC.

SA12. High Energy Bremsstrahlung and Pair Production.* J. W. DEWIRE AND L. A. BEACH, *Cornell University.*—The Bremsstrahlung spectrum from a ½-mil tungsten target bombarded with electrons from the synchrotron has been measured with an electron pair spectrometer. The beam passes through $\frac{1}{16}$-inch aluminum, ½-inch Lucite, and 8 feet of air before striking the thin gold radiator of the spectrometer. The shape of the spectrum is in good agreement with the Bethe-Heitler theory down to 30 Mev, the lowest point measured. The upper energy endpoint was determined to be 309 ± 5 Mev. The spectrum from a 40-mil tungsten wire shows essentially the same shape with possibly somewhat fewer photons near the maximum energy.[1] The sharing of energy between members of pairs produced in aluminum and gold by 270-Mev photon has also been observed. Preliminary results give agreement between the distributions from the two radiators but a somewhat larger contrast between equal and unequal sharing than predicted by the Bethe-Heitler theory. Further work is in progress to study possible instrumental effects on this result.

* Assisted by the joint program of the ONR and AEC.
[1] Powell, Hartsough, and Hill, Phys. Rev. 81, 213 (1951).

SATURDAY MORNING AT 9:45

Wardman Park, Continental Room

(D. J. HUGHES presiding)

Neutrons; Fission

T1. Direct Measurement of Gravity Acceleration of Neutrons.* A. W. MCREYNOLDS, *Brookhaven National Laboratory.*—Gravity acceleration of neutrons was measured directly by determining the free fall of a highly collimated beam from the Brookhaven reactor. Separation was measured between two beams of different velocity but defined by the same collimating system. Thermal neutrons, of velocity 4×10^5 cm/sec, were compared at 12.5 meters range with neutrons of 9×10^4 cm/sec

and less, filtered through BeO, and at 100 meters range with fast neutrons of velocity 6×10^8 cm/sec and greater, selected by inserting a cadmium absorber. Separations are of the order of 1–2 mm in both cases and agree within the experimental error of about 10 percent with the usual value of g.

* Research carried out under contract with the AEC.

T2. Energy Spectrum of Neutrons Produced in Light Elements by 385-Mev Protons.* W. F. GOODELL, JR., H. H. LOAR, AND R. P. DURBIN, *Columbia University.*—Measurements have been made of the energy distributions of neutrons produced in light elements by 385-Mev protons. The neutrons were produced inside the cyclotron and were collimated in the forward direction by a 4-inch pipe embedded in 6 feet of lead and concrete shielding. The neutrons were detected by measuring the difference in the number of recoil protons from polyethylene and carbon targets. Measurements were made at an angle of 45° in the laboratory system. The energies of the protons were determined by differential measurements of the ranges in copper. A defining telescope of proportional or scintillation counters was followed by an absorber and a 2-inch scintillation counter. The last counter was so desensitized as to detect only protons near the end of their range. Corrections were made for nuclear absorption and coulomb scattering in the absorber. The corresponding distributions of neutron energies were then calculated, assuming previously published $n-p$ scattering cross sections at 40, 90, and 270 Mev at 45°. Preliminary analysis of the data indicates a strongly peaked neutron energy distribution from beryllium and a less strongly peaked distribution from carbon. For a 2-inch beryllium target, the peak of the distribution lies near 310 Mev and has a half-width of approximately 100 Mev. The average flux over the peak at the detector was of the order of 100 neutrons/cm²/sec/Mev.

* Assisted by the joint program of the ONR and AEC.

T3. A Simplified Theory of Neutron Scattering and Capture. T. A. WELTON, *Oak Ridge National Laboratory.*—The elastic scattering of slow neutrons by nuclei is conveniently described by a single real phase shift. A simple differential equation for the energy variation of this phase shift is derived from first principles. Integration of this equation yields directly the usual Breit-Wigner one-level formula for elastic scattering. A more complete treatment seems to yield a series of resonances, approximately equally spaced in energy. The predicted spacing agrees quite well with experiment in at least one reliable set of measurements, but the existence of marked discrepancies in other cases casts strong doubt on the general validity of this expression for the level spacing. Neutron capture is treated by making precise the concept of the time spent inside the nucleus by the incident neutron. It is then assumed that during the time spent within the nucleus, the compound nucleus has a constant probability per unit time of radiating. There results a neutron capture cross section which has the same maximum value and width as that given by the Breit-Wigner formula. The details of the curve are different, and this point is receiving further investigation.

T4. Resonant Scattering of Thermal Neutrons. B. N. BROCKHOUSE, M. BLOOM,* AND D. G. HURST, *Chalk River Laboratory.*—The scattering of neutrons from the resonant absorbers cadmium, indium, samarium, and gadolinium has been investigated with a crystal spectrometer. An annular bank of BF_3 counters was used as detector. The counting rate N for a "thick" specimen was compared with the rate N_T for a "thin" sample of vanadium. The absence of coherent scattering in vanadium makes it a suitable standard. The ratio N/N_T is proportional to σ_{sc}/σ_a for the specimen, the constant of proportionality being determined from the geometry. For cadmium from 0.02 to 0.4 ev this ratio is given accurately by a Breit-Wigner formula with accepted constants and 6.5×10^{-12} cm as the potential scattering length in the interference term. The spin of the compound nucleus Cd^{114} is unity, in agreement with Beeman.[1] The spin of the compound nucleus In^{116} is four if σ_0 is taken as 26,000 barns. The spins of the target nuclei Sm^{149} and Gd^{157} are not known, but the signs of the spin changes and possible values of the original spins can be given.

* Now at University of Illinois.
[1] W. W. Beeman, Phys. Rev. **72**, 986 (1947).

T5. Neutron Capture in Pb^{206}. B. B. KINSEY AND G. A. BARTHOLOMEW, *Chalk River Laboratory.*—Some recent measurements on the gamma-rays of neutron capture in Pb show that the simplicity of the spectrum from Pb^{207} is shared by Pb^{206}. The intensities of the gamma-rays at 6.73 and 7.38 Mev produced by neutron capture in Pb^{206} and Pb^{207}, respectively, have been compared using samples of ordinary lead and a radiogenic lead in which the concentration of Pb^{206} was 89 percent. The thermal neutron capture cross sections of our samples have been measured at the Atomic Energy Research Establishment, Harwell, England. From these results we find that the ratio of the gamma-ray intensities in the radiogenic lead (in which they are most easily measured) is equal to the ratio of the rates of neutron capture in the two isotopes. Since roughly one photon of 7.38 Mev is produced per neutron captured in Pb^{207}, it follows that the intensity of the 6.73-Mev gamma-ray is about one photon per capture in Pb^{206}.

T6. Fast Neutron Capture Cross Sections and Shell Structure.* D. J. HUGHES AND R. C. GARTH, *Brookhaven National Laboratory,* AND C. EGGLER, *Argonne National Laboratory.*—The capture cross section for one-Mev neutrons is a direct measure of the average level density in the compound nucleus at an excitation energy equal to the neutron binding plus one Mev. Previous cross section results[1] obtained with fission neutrons (effective energy one Mev) have shown clearly the increase in level density with atomic weight and the marked decrease in level density (associated with decreased neutron binding energy) at the nuclear shells. The measurements have been continued with special attention to nuclei near the complete shells. The level density for nuclei just above the 82 neutron shell is low but rises to normal at 90 neutrons. The low cross sections for several Ru and Mo isotopes indicate a hitherto unreported shell at 58 neutrons. Several isotopes with neutron number near 110 exhibit a normal level density. The explanation of the observed cross section variation involves both the single particle nuclear model (low binding for neutrons in excess of filled shells) and the statistical model (rapid variation of level density with excitation energy).

* Research carried out under contract with AEC.
[1] D. J. Hughes and D. Sherman, Phys. Rev. **78**, 632 (1950).

T7. Low Energy Neutron Cross Sections of Bismuth.* H. PALEVSKY AND D. J. HUGHES, *Brookhaven National Laboratory,* AND C. EGGLER, *Argonne National Laboratory.*—The low energy scattering, absorption, and activation cross sections of bismuth are being measured in order to determine the properties of a bismuth mirror. Several noteworthy results, which have no special reference to mirrors, have been obtained from the measurements to date. The absorption cross section (at 2200 m/sec velocity), measured by the effect of bismuth on pile reactivity, is 30 mb, while the activation cross section (for the 5-day Bi^{210}) is only 15 mb. Chemical and spectroscopic analysis, as well as intense neutron irradiation, reveal no impurities in the various purified bismuth samples used. It is possible that the excess absorption leads to the long lived alpha-emitter ascribed by Neumann, Howland, and Perlman[1] to an isomeric state of Bi^{210}, although such a large cross section would imply an exceedingly long lived isomer ($\sim10^6$ years).

The inelastic as well as the spin dependent scattering is being measured with the Brookhaven slow chopper for neutrons of wavelength 6 to 23A. In this wavelength range the inelastic scattering departs widely from the proportionality to λ that is expected theoretically and that has been observed in several other materials.

* Research carried out under contract with AEC.
[1] Neumann, Howland, and Perlman, Phys. Rev. **77**, 720 (1950).

T8. The Neutron Resonance in V^{51} at 3300 ev. S. P. HARRIS, *Argonne National Laboratory.*—Using the high speed resonance region neutron velocity selector,[1] direct measurements have been made on the resonance in vanadium.[2,3] Hamermesh and Muehlhause give an energy of ~2700 ev for the V^{51} resonance from the correlation of cross-section values in the one-level Breit-Wigner formula. Velocity selector transmission curves indicate a strong dip at ~3300 ev, in good agreement with the value of Hamermesh and Muehlhause. Transmission curves for vanadium and for several other elements having resonances will be presented and a brief description of the machine will be given.

[1] W. Selove, Phys. Rev. **76**, 187A (1949).
[2] S. P. Harris and A. S. Langsdorf, Phys. Rev. **74**, 1216A (1948).
[3] M. Hamermesh and C. O. Muehlhause, Phys. Rev. **78**, 175 (1950).

T9. Internal Conversion of Neutron Capture γ-Rays. I. C. O. MUEHLHAUSE, *Argonne National Laboratory.*—Low energy internal conversion electrons from neutron capture γ-rays have been reported for Cd, Gd, and Br.[1] The work to be described in this paper was performed at Argonne Laboratory in April, 1948. At that time the author made a survey of strong neutron absorbers in an attempt to search for other examples of this phenomena. Thin films (~1 mg/cm^2) of Cd, Gd, Sm, Eu, Dy, and Hg were placed in contact with a photographic plate and bombarded in a thermal neutron flux from the Argonne heavy water reactor. In each case an intense blackening of the plate resulted which could be removed by interposing a few mg/cm^2 of either Al or Be between the absorber and plate. This and other control experiments indicated a prompt soft charged radiation to be present in the capture process which was identified as an internal conversion electron. Absorption measurements of the radiation yielded electron energies of the order of 100 to 500 kev. Since in all the materials examined low energy electrons were found in abundance, it is concluded that low energy capture states having a long lifetime (~10^{-10} sec) are a common occurrence.

[1] T. H. Davies and S. Wexler, Brookhaven National Laboratory Report C-7, Conference on Chemical Consequences of Nuclear Transformations (1948).

T10. Internal Conversion of Neutron Capture Gamma-Rays. II. CARL T. HIBDON AND C. O. MUEHLHAUSE, *Argonne National Laboratory.*—Low energy neutron capture gamma-rays from Gd and Sm^{149} have been measured with a 180° focusing permanent magnet beta-spectrograph. A well-collimated beam of neutrons from the Argonne heavy water reactor passes through the spectrograph and irradiates a neutron absorber which is located in the usual source position. Internal conversion electrons from this absorber are focused on no-screen x-ray film. Several lines resulting from a Gd absorber are easily observed and are associated with two gamma-rays, one of 80 kev and another of 90 kev. The K, L_2, L_3, and M lines occur for the 80-kev gamma-ray and the K and L_3 lines for the one at 90 kev. A faint line always observable at a higher energy could not be associated with either of these two gamma-rays. If interpreted as the K-line of a third gamma-ray, the energy of this gamma-ray is 185 kev. Only one line from a Sm^{149} absorber is observed with this instrument, and if interpreted as a K-line, the gamma-ray has an energy of 341 kev.

T11. Paramagnetic Scattering of Neutrons by MnF_2 and MnO.* P. J. BENDT, L. J. RAINWATER, AND W. W. HAVENS, JR., *Columbia University.*—Ruderman[1] obtained experimental confirmation of paramagnetic neutron scattering and checked the free-ion integral form factor derived by Halpern and Johnson[2] by making neutron transmission measurements on MnF_2 and MnO. Shull *et al.* (ORNL 481) have confirmed the free-ion differential form factor and have studied magnetic reflections from MnO and other manganese compounds when these were cooled below their Curie temperature. The neutron scattering experiments to be described were for the purpose of studying the intermediate situation, when the magnetic ions are neither entirely uncoupled, nor rigidly locked in an antiferromagnetic array. In the analysis of the results, an attempt has been made to separate inelastic effects from coherent effects due to short-range ordering of the ion spins. The parameters which could be varied in this experiment were the angle of scattering, 18° or 33°; the neutron wavelength, 1 to 5.5 angstroms, determined by the Columbia Neutron Velocity Selector; the strength of the exchange coupling between Mn^{++} ions, which is stronger in MnO than in MnF_2; and the sample temperatures, between 107°K and 610°K.

* Supported in part by the AEC.
[1] J. W. Ruderman, Phys. Rev. **76**, 1572 (1949).
[2] O. Halpern and M. H. Johnson, Phys. Rev. **55**, 898 (1939).

T12. Long Period Delayed Neutrons. J. W. KUNSTADTER, J. J. FLOYD, L. B. BORST, AND G. J. WEREMCHUK, *Brookhaven National Laboratory.*—The neutron density at a point in the Brookhaven reactor has been measured with indium foils as a function of time after a rapid shutdown. Neutrons of low yield and long half-life were observed after the decay of the groups of up to 55-second half-life previously reported.[1] Three groups of neutrons were found by a peeling-off process on data obtained after varying lengths of reactor operation time. The half-lives are about 3, 12, and 120 minutes, and the yields relative to the 55-second group are $1:3\times10^{-4}:10^{-7}:5\times10^{-9}$, with no correction for the unknown neutron energies. The limits of error are estimated to be 15 percent in the half-lives and 25 percent in the yields. No known fission product γ-rays are recorded which can give photo-neutrons or photo-fission with these characteristics.

[1] Hughes, Dabbs, Cahn, and Hall, Phys. Rev. **73**, 111 (1948). Sun, Charpie, Pecjak, Jennings, Nechaj, and Allen, Phys. Rev. **79**, 3 (1950).

T13. Velocity Distribution of Fission Fragments.* R. B. LEACHMAN, *Los Alamos Scientific Laboratory.*—The velocity distribution of fragments from the slow neutron fission of U^{235} has been obtained by time-of-flight measurements. Two well-defined peaks were found corresponding to the light and heavy fragment groups. When compared with the velocity distribution calculated from coincidence ionization data of fragments in argon,[1] the measured distribution indicates that in argon the energy-ionization ratios w_L and w_H of the most probable light and heavy fragments exceed w of uranium alpha-particles by factors of 1.05 and 1.12, respectively. On this basis, the average kinetic energy of fission is about 12 Mev greater than the 156 Mev[1] found by the customary conversion of ionization to energy by w of alpha-particles. The ratio $w_L/w_H=0.938$ determined from velocities is in reasonable agreement with the values 0.963 and 0.964 found by other methods.[2]

* Work performed under auspices of the AEC.
[1] D. C. Brunton and G. C. Hanna, Can. J. Research **A28**, 190 (1950).
[2] Knipp, Leachman, and Ling, Phys. Rev. **80**, 478 (1950).

SATURDAY MORNING AT 9:45

NBS, East Building

(E. U. CONDON presiding)

Physical Problems Solved by Computing Machines

U1. Crystal-Structure Computations on X-RAC. RAY PEPINSKY, *Pennsylvania State College.* (30 min.)

U2. Statistical Fields for Atoms. L. H. THOMAS, *Watson Scientific Laboratories.* (30 min.)

U3. Droplet Dynamics and Nuclear Fission. J. A. WHEELER AND D. L. HILL, *Los Alamos Scientific Laboratory.* (30 min.)

U4. Solution of X-Ray Diffusion Problems with the SEAC. L. V. SPENCER, *National Bureau of Standards.* (30 min).

U5. Formation of the Elements in the Expanding Universe. R. A. ALPHER AND R. C. HERMAN, *Johns Hopkins University.* (30 min.)

SATURDAY MORNING AT 9:45

Shoreham, Main Ballroom

(C. C. LAURITSEN presiding)

Invited Papers

V1. Meson Masses and the Energetics of Meson Decay. WALTER BARKAS, *University of California, Berkeley.* (30 min)

V2. *V*-Particles and Their Disintegration Products. R. B. LEIGHTON, *California Institute of Technology.* (30 min.)

V3. Precision Measurements with a New Mass-Spectrograph. S. A. GOUDSMIT, *Brookhaven National Laboratory.* (30 min.)

SATURDAY MORNING AT 9:45

Shoreham, West Ballroom

(G. C. WICK presiding)

Nuclear Theory, I

W1. Influence of Nuclear Size on X-Ray Fine Structure.* A. L. SCHAWLOW AND C. H. TOWNES, *Columbia University.*—Christy and Keller[1] calculated the fine structure constant, α, from the x-ray doublet separation L_{II}-L_{III}. When their value is corrected for the anomalous spin moment of the electron,[2] it gives $1/\alpha=137.11$, which is higher than the average of other accurate measurements (137.0435 ± 0.0007). One factor which was not considered in these calculations is the finite size of the nucleus. This reduces the binding energy of a $p_{\frac{1}{2}}$ electron more than that of a $p_{\frac{3}{2}}$ and so reduces the doublet splitting for a given value of α. The correction has now been calculated and is found to vary from 0.01 percent for $Z=60$ to 0.2 percent for $Z=95$. After applying this correction, the value obtained for $1/\alpha$ is 137.04 in good agreement with other determinations. Since the percentage correction varies very rapidly with Z it can be separated from other atomic effects. The available data is not as accurate as might be desired, but indicates such a variation. The effect is related to isotope shifts in optical spectra but measures the total change of electronic energies rather than differences between isotopes.

* Work supported by the AEC.

[1] R. F. Christy and J. M. Keller, Phys. Rev. 61, 147 (1942).

[2] H. A. Bethe and C. Longmire, Phys. Rev. 75, 306 (1949).

W2. Evaluation of the Metric for Liquid Drop Configuration Space. DAVID L. HILL, *Vanderbilt University.*—The successive shapes of a deforming liquid drop nuclear model define the trajectory of its system point in an n-dimensional configuration space defined by parameters such as the α_i's of the expression describing a cylindrical symmetric surface:

$$R(\mu)=a_0[1+\sum_{i=1}^{n}\alpha_i P_i(\mu)].$$

The deformation potential energy surface,[1] constructed in the corresponding $(n+1)$-dimensional space, enables us to determine this dynamical path for any initial motion, provided the metric of the configuration space is known. I shall display a procedure for evaluating the elements of the metric tensor by employing the connection between the parameters of the expansion for velocity of internal motion and the time variation of the shape coordinates α_i. We may then specify, for example, the path of steepest descent of the system point away from the saddle point of the energy surface, corresponding to that development of the nuclear surface which leads most directly from the shape of unstable equilibrium toward fission.

[1] N. Bohr and J. A. Wheeler, Phys. Rev. 56, 426 (1939); S. Frankel and N. Metropolis, Phys. Rev. 72, 914 (1947).

W3. Ionization Statistics. J. K. KNIPP, *Iowa State College.*—The ionization produced by electrons, protons, alpha-particles, and other atomic particles including fission fragments and recoiling atoms from nuclear decay can be described statistically in terms of the fundamental processes of a single atomic or molecular collision. The basic equations, which are the result of the application of the usual rules for the composition of probabilities, relate the probabilities of obtaining certain numbers of ion pairs to the corresponding probabilities after a single collision. For example, consider a gas particle in its own gas and suppose all collisions either cause ionization with energy loss ω^s, for which the probability is $Q_i(E)$, or give rise to recoil atoms of energy E^1, with the differential probability $Q(E, E^1)dE$. Then the probability $P(E, I)$ that a particle of energy E produce I ion pairs when stopped in the gas is readily described in terms of $Q_i(E)$ and $Q(E, E^1)$. The calculation of moments from the basic equations leads to integral equations for the average total ionization, mean square fluctuation, etc. Thus, for the example given, the average total ionization satisfies the equation

$$I(E)=Q_i(E)[I(E-\omega^s)+1]+\int_0^E dE^1 Q(E, E^1)[I(E-E^1)+I(E^1)].$$

The mean square fluctuation satisfies a similar equation.

W4. Excitation and Ionization by Electrons. T. EGUCHI AND J. K. KNIPP, *Iowa State College.*—An electron in its passage through a gas leaves the atoms and molecules in states of excitation, dissociation, and ionization. The number of atoms or molecules in a particular condition is subject to a statistical treatment wherein the fundamental processes are the collisions of the primary electron, and the ejected electrons, with the unexcited constituents of the gas. Were the solutions of the basic equations known, averages and mean square fluctuations could be calculated directly. Instead, nonhomogeneous integral equations are obtained for these quantities, the solutions of which are asymptotic to linear functions of the energy. The coefficients of the energy in the asymptotic expressions are simply related to the energy loss per excitation, energy loss per ion pair, deviations from poisson fluctuations, and other physically interesting parameters of the statistics. The constant terms in the asymptotic expressions are the excitation defects, ionization defects, etc. Explicit expressions which are obtained for certain of these quantities are rather insensitive to the exact form of the solutions of the integral equations.

W5. Range-Straggling Due to Ionization. H. W. LEWIS, *Institute for Advanced Study.**—The problem of range-straggling of a fast nonrelativistic heavy particle, due to ionization and excitation, has been re-examined to determine the region of validity of the usual gaussian approximation to the range distribution. This approximation may be expected to be less accurate than is commonly thought, for several reasons, of which the most cogent is illustrated by the following typical example: if a 100-Mev proton is stopped in aluminum, 35 percent of the variance (mean square dispersion) in range is provided by collisions in which it loses more than half the maximum energy it is possible to lose in a single event. The average number of such collisions is nine, which is not an extremely large number. Indeed, 20 percent of the variance arises from a single collision. Consequently, the central limit theorem of statistics, which requires that each even contribute a vanishing part of the variance, is inapplicable. An exact solution of the straggling problem, in a simplified model, will be discussed, along with the relation between this model and reality.

* On irregular leave from the University of California, Berkeley.

W6. On the Theory of Multiple Scattering.* GEORGE YEVICK, *Stevens Institute of Technology.*—The general integral-differential equation for the distribution function of a proton beam throughout a scattering material is converted into an integral equation by obtaining the Green's function (straight-line Green's function) for the differential part of the equation and considering the integral part as a source term. The integral equation is solved by iteration. As an initial trial function, the small-angle coulomb distribution function with energy loss obtained by Eyges[1] is used. One interprets this physically in the following way: the particles are smeared out over space in a manner given by the small-angle distribution, suffer a large angle nuclear or coulomb collision, and then travel in a straight line via the Green's function. The integrals must be solved in an approximate manner. For the case of finite domains of material a surface integral must be evaluated. It is also possible to convert Eyges' solution into a Green's function, which physically means that after a large angle scattering the particle is multiply small-angle scattered. The integrals, however, become rather lengthy to handle. The effect of absorption, which takes care of star production and inelastic scattering, can be treated by the above methods.

* A major portion of this work was done during the summer of 1950 at the Nevis Cyclotron Laboratory.

[1] L. Eyges, Phys. Rev. **74**, 1534 (1948).

W7. Gamma-Ray Transmission through Finite Slabs.* GLENN H. PEEBLES, *Rand Corporation* (Introduced by M. S. PLESSET).—The transmission of photons through a plane slab of finite thickness but infinite extent is the sum of the transmissions with 0, 1, 2, etc., scatterings. If the transmission in the first few scatterings is known and comprises 50–60 percent of the total, then the total transmission can be estimated with accuracy adequate for most purposes. A process is described for calculating the transmission with $k+1$ scatterings when the transmission with k scatterings is known over sufficiently wide ranges of three parameters: slab thickness, incident energy, and incident direction. The magnitude of the task of developing the three variable system is offset by the amount of information gained. Estimates of the transmission for mono-energetic, mono-directional incident beams are given for slabs of lead and iron. Thickness ranges from 0 to 20 mean free paths, incident energy from 1 to 20 mc^2 and incident angle from 0 to 90°. One easily uses these estimates to find the transmission for beams whose photons are distributed continuously over incident energy and angle. Although the basic calculations are for lead and iron, they yield estimates of the transmission for many other materials.

* This work was supported in part by the AEC.

W8. *Z*-Dependence of the Cross Section for Capture of Photons by Nuclei. J. HEIDMANN, *Cornell University* (Introduced by H. A. BETHE).—Experiments on the emission of photo-neutrons have shown anomalies for light nuclei (Z from 8 to 20) consisting of fluctuations between even and odd nuclei and generally small cross sections. We have applied the theory of the compound nucleus to this problem for gamma-rays of 10 to 20 Mev. Owing to the high binding energy of the neutron, light nuclei are found to emit mainly protons. The so-called resonance observed in the formation of radioactive isotopes by gamma$-n$ reactions is explained by the competition by emission of two neutrons at the higher energies. To avoid assumptions on the energy dependence of the cross section, the theory is compared with experiments using 17-Mev photons from Li detected by BF_3 counters.[1] The measured cross section for light nuclei, Cu, and heavy elements with single isotopes is divided by the calculated number of neutrons emitted from the compound nucleus; the result is, within 25 percent, proportionate to Z, in agreement with theoretical expectation.

[1] McDaniel, Walker, and Stearns, Phys. Rev. **80**, 807 (1950).

W9. On Nuclear Disintegration by Positron—K Electron Annihilation. S. C. CHEN AND R. D. PRESENT, *University of Tennessee.*—A positron with insufficient energy to excite or disintegrate a nucleus by collision may annihilate a K electron of an atom with subsequent excitation or disintegration of its nucleus. If the positron energy is close to threshold for the process, competition from two-quantum annihilation does not occur. The process is of first order and, apart from the occurrence of negative energy states, is the reverse of internal conversion. The cross section may be factored into a cross section for annihilation with emission of a photon converging on the nucleus times a probability for nuclear disintegration. The latter is essentially the ratio of the photo-disintegration cross section to the S-wave black-body absorption cross section $\pi\lambda\!\!\!^{-2}$. The annihilation cross section in light elements has been calculated in the Born approximation using the retarded interaction corresponding to converging spherical waves of electric dipole radiation (the nucleus acts as a sink for these waves, in addition to conserving momentum). For large incident energy of the positron the difference between positive and negative energy states can be neglected and the cross section obtained by detailed balancing from the internal conversion coefficient. The cross section for disintegration of Be^9 is $\sim 10^{-24}$ cm^2 near threshold; for heavier nuclei it would be larger ($\sim Z^3$).

W10. A Note on Angular Distribution of Gamma-Radiation from 16-Mev C^{13*}. G. B. ARFKEN AND L. C. BIEDENHARN, *Oak Ridge National Laboratory.*—In the reaction $B^{11}(p, \gamma)C^{12}$ the 16-Mev crossover γ is observed to be isotropic, while the 12-Mev γ follows a $1+0.15\cos^2\theta$ distribution.[1] It appears to be a general result that if one has isotropic 2^L pole radiation from a state of spin J (magnetic substates m_J with random phase) and $L \geq J-\frac{1}{2}$, then all gamma-radiation from that state must be isotropic. The condition $L \geq J-\frac{1}{2}$ has been proven necessary and is sufficient in all cases considered here. This lemma applies to C^{12} and in general whenever the final nuclear state in the isotropic γ-transition has $J=0$ or $\frac{1}{2}$. The possibility of a small undetected anisotropy in the 16-Mev γ has been considered in detail. It is concluded that the 16- and 12-Mev γ's must come from different states of C^{13}.

[1] High Voltage Group, Oak Ridge National Laboratory (private communication).

W11. Wave Functions in Momentum Space. E. E. SALPETER, *Cornell University.*—The momentum-space wave functions for a nonrelativistic two-body problem with a phenomenological interaction potential satisfy a well-known integral equation. A general prescription is given for finding suitable trial wave functions, which depend on some adjustable parameters. Reasonable values for these parameters are found by iteration of the wave function for particularly simple values of the momentum. Successive approximations are then obtained for the wave functions by repeated iteration of the integral equation. The method outlined is similar to some methods used previously,[1] but is not based on a variational principle and is more suitable for numerical work. For the deuteron ground-state, using central Yukawa, exponential, and square well potentials, accurate momentum-space wave functions are being calculated in numerical form. The application of the method to scattering problems, and to a four-dimensional integral equation obtained in a relativistic treatment of the two-body problem, will be discussed.

[1] N. Svartholm, Thesis (Lund) 1945; B. A. Lippmann and J. Schwinger, Phys. Rev. 79, 469 (1950).

W12. Relativistic Theory of Interaction at a Distance Between Particles. L. H. THOMAS, *Watson Scientific Computing Laboratory.*—A nonrelativistic classical dynamical system with a finite number of degrees of freedom may be specified in terms of canonical variables by a hamiltonian function. If the system admits the newtonian group, the motion of the center of mass can be separated. If the hamiltonian separates for large values of certain variables, the system can be regarded as a system of particles, perhaps spinning, interacting at a distance. Using Lie theory we can extend such systems to admit the Lorentz group, and we have relativistic classical dynamical systems, in exactly the same variety as nonrelativistic systems. Separation of the center of mass motion is still possible. Particles in interaction do not have invariant world lines as the transformations involve all the variables, and the usual argument against the possibility of such systems does not apply. The contact transformations corresponding to change of Lorentz frame are of the form of extended point transformations in terms of variables that, for non-interacting particles, are physically momenta. The usual quantization can then be carried out. The transformations involve square roots, and the systems cannot in general be changed to wave equations similar to the Dirac equations for an electron.

W13. The Kinetic Energy Operator for the Nuclear Three-Body Problem. B. T. DARLING AND B. R. LINDEN,* *The Ohio State University.*—Darling's method[1] of separating rotational from radial motion by use of group operators has been applied to the three-body problem.[2] The coordinates chosen were those of the center of mass, the interparticle distances, and the infinitesimal rotations about the coordinate axes. The kinetic energy expression consists of terms involving only the radial distances and derivatives, terms quadratic in the angular momentum operators (similar, in form, to the asymmetric rotator), and mixed terms involving radial derivatives and angular momentum operators (coriolis terms). The pure radial term is equivalent to the Hylleraas[3] expression and is the only contribution to the kinetic energy for S states. With moving axes defined by taking the origin at the center of mass, the x axis through one of the particles, and the plane of the particles as the $x-y$ plane, pure radial equations were obtained by replacing the angular momentum operators by their matrix representatives. In these equations terms quadratic in the angular momentum matrices play the role of centrifugal forces.

* AEC Predoctoral Fellow.
[1] B. T. Darling, Doctoral Thesis, University of Michigan, 1939.
[2] B. R. Linden, Master's Thesis, Ohio State University, 1949.
[3] Z. Physik 54, 347 (1929).

W14. The Pure Radial Equations for Nuclear Three-Body Problem. B. R. LINDEN* AND B. T. DARLING, *The Ohio State University.*—The exact radial equations for the nuclear three-body problem have been determined under the assumption of a charge independent potential of the most general static exchange central interaction and a static non-exchange tensor interaction. The kinetic energy operator is that discussed in a previous paper[1] by the same authors. Only those S, P, and D states mix which have even K (the projection of orbital angular momentum along the body-fixed z-axis associated with the symmetric rotator function $\theta(L, M, K)$) as is predicted on the basis of parity. The eight radial wave functions satisfy a set of eight simultaneous differential equations. These equations seem to indicate that the states have the following order of decreasing magnitude: (a) the ^3S state, ψ_1, with spins antisymmetric for like particles; (b) the ^1S state, ψ_2, with spins symmetric for like particles; (c) the ^1D states with $K=\pm 2$; (d) the ^3D state with $K=0$; (e) the ^1P and ^3P states. The ^1D states are apparently determined mainly by ψ_2. It does not appear that the question of relative phases can be disregarded.

* AEC Predoctoral Fellow.
[1] See preceding abstract.

SATURDAY AFTERNOON AT 2:00

Shoreham, West Ballroom

(J. H. VAN VLECK presiding)

Nuclear Theory, II

WA1. Low Energy Photo-Meson Production in Hydrogen. S. D. DRELL, *Stanford University.*—Berkeley experiments indicate approximate equality of the π^0 and π^+ production cross sections. Calculations based on a weak coupling perturbation treatment of the meson-nucleon interaction predict π^0 production to be reduced by $\sim(\mu/M)^2$ relative to π^+ production for energies at which the Berkeley experiments are performed ($\sim$320 Mev). We avoid this perturbation approximation. With a Bloch-Nordsieck type canonical transformation we obtain a solution to the hamiltonian equation that involves no assumption concerning the largeness or smallness of $g^2/4\pi$. The approximations involved are neglect of nucleon recoil and treatment of spin and charge matrices as classical unit vectors. Handling the electromagnetic field by standard perturbation theory, we use this solution to calculate the matrix elements for photo-production. In evaluating the matrix elements we must use a finite source cutoff to compensate neglect of nucleon recoil. We obtain qualitative agreement with the observed equality of π^0 and π^+ production cross sections with a choice of $g^2/4\pi\sim 1-2$ and of source radius of the order of a nucleon Compton wavelength. We also obtain an angular distribution and energy dependence for the production cross sections in accord with observation.

WA2. π^- Meson Reactions in Tritium. E. R. CAIANIELLO AND A. M. L. MESSIAH, *University of Rochester.*—It has been shown[1] that the π^- meson reactions in hydrogen and deuterium are sensitive to spin and parity of the π-meson. Qualitatively, the ratios can be predicted on the basis of angular momentum and parity selection rules. We have searched for similar selection rules in the reactions: (1) $\pi^-+H^3\rightarrow 3n$ and (2) $\pi^-+H^3\rightarrow 3n+\gamma$. No selection rules follow from the exclusion principle alone. However, if the ground-state space wave function of tritium is totally symmetric, reaction (1) is forbidden for scalar and pseudovector π^- mesons. The small non-symmetric contribution to the tritium wave function which may exist[2,3] does not alter this conclusion. Since reaction (2) is allowed for all meson fields, the relative probabilities of (1) and (2) should help decide between the pseudovector and pseudoscalar fields for the π-meson.[1]

[1] S. Tamor and R. E. Marshak, Phys. Rev. **80**, 766 (1950).
[2] F. Villars, Helv. Phys. Acta **20**, 476 (1947).
[3] R. L. Pease and H. Feshbach (private communication).

WA3. Pion Scattering with Exchange. M. L. GOLDBERGER, *University of Chicago.*—The reactions $\pi^-+P\rightleftarrows N+\pi^0$ and $\pi^++N\rightleftarrows P+\pi^0$ will be discussed on the basis of a simple model proposed by E. Fermi. The scattering processes with and without charge exchange are treated, using a formalism essentially identical to nuclear reaction methods of Wigner and Eisenbud.[1] It is assumed that outside a region of radius equal to the meson Compton wavelength there is either no interaction or only coulomb interaction between pions and nucleons. The inside problem is specified in terms of three parameters in the form of boundary conditions at the critical radius. The description is limited to low energy processes and is made entirely without meson theory. The lifetime of a π^- bound in a K orbit is computed. From this computation, an estimate of the strength of the coupling can be deduced. It is shown that charge exchange processes are improbable in both the very weak and very strong coupling limits. The above description is admittedly highly speculative but may provide a simple method of correlating experimental results without using detailed meson theories.

[1] E. P. Wigner and L. Eisenbud, Phys. Rev. **72**, 29 (1947).

WA4. A Quantitative Analysis of the Impulse Approximation. G. F. CHEW, *University of Illinois,* AND G. C. WICK, *Carnegie Institute of Technology.*—The impulse approximation[1] is a generalization of Fermi's method for treating the scattering of slow neutrons by bound protons.[2] It extends the method to energies at which many partial waves may be scattered and takes into account a possible energy dependence of the two-body scattered amplitude. The general criterion for the validity of the impulse approximation has now been drived on the basis of an integral equation, and the order of magnitude of the accuracy can be determined. In particular, it can be shown that for 100-Mev neutrons scattered by deuterons, an accuracy of $\sim$15 percent is to be expected. For still higher energies, it becomes reasonable to apply the method to the interaction of nucleons with even more tightly bound nuclei.

[1] G. F. Chew, Phys. Rev. **80**, 196 (1950).
[2] E. Fermi, Ricerca sci. VII–II, 13 (1936).

WA5. Nuclear Saturation and Magic Numbers in Terms of a Non-Linear Meson Theory.* L. I. SCHIFF, *Stanford University.*—Work reported earlier under the above title[1] has been extended with a better model for nuclear matter, in which a nucleon is embedded in a uniform meson source. Neutrons and protons are regarded as equal sources for a non-linear neutral scalar meson field, and a variation method is used. Two parameters that specify the single nucleon source strength, and one parameter that specifies the non-linearity of the meson field, are chosen so that the total energy (potential and kinetic) of nuclear matter has a minimum at the observed density and equal to 42 percent of the observed energy. The two-nucleon interaction in free space then has a short-range repulsive core, and has 45 percent of the observed strength (as measured by the square of the zero energy phase integral $\int(-V)^{\frac{1}{2}}dr$). When embedded in nuclear matter, this calculated two-nucleon interaction strength is reduced to 38 percent of its free space value. These results indicate that the theory is capable of accounting qualitatively for nuclear saturation and for the independent-nucleon model that leads to shell structure and magic numbers.

* Assisted by the joint program of the ONR and AEC.
[1] L. I. Schiff, Phys. Rev. **80**, 137 (1950).

WA6. Short-Range Correlations in Nuclear Structure. KEITH A. BRUECKNER, *Institute for Advanced Study,* AND KENNETH M. WATSON, *University of California, Berkeley.*—It has been observed experimentally by Panofsky that the capture of Pi-mesons in deuterium[1] leads to a radio of non-radiative to radiative capture of seven to three, while in carbon the ratio is greater than two hundred to one. It is possible to show that the difference can be attributed almost entirely to the existence of stronger short-range correlations in nucleon positions in carbon than in deuterium. The explicit calculation involves an integral over the coordinates of the initial and final nuclei which may be simplified by application of an approximate closure rule to the wave functions of the final nuclei. Further simplifications can be made by introduction of the transition matrix leading to meson absorption, as de-

duced from the deuteron absorption experiments. The remaining integral is interpreted as representing the probability of finding in contact the two nucleons involved in the act of absorption. Comparison with experiment shows that this probability is much greater than the random probability based only on nuclear volume, or that deduced, for example, from a Fermi distribution. This effect is presumably due to the strong short-range nucleon-nucleon interaction.

[1] W. K. H. Panofsky, Phys. Rev. 81, 565 (1951).

WA7. Dipole Oscillator-Strength Sum Rules for Relativistic Systems. L. L. FOLDY, *Case Institute of Technology.*—The well-known Thomas-Reiche-Kuhn sum rule for electric dipole oscillator strengths has been very useful in studying the interaction of electromagnetic radiation with atoms and has more recently been applied to the analysis of the nuclear photo-effect. An analagous sum rule can be derived for the interaction of electromagnetic radiation with the meson field about a nucleon as well as to more general electromagnetic interactions with relativistic charged fields. In general, the oscillator-strength sum involves the expectation value of a space integral of the commutator of the operators for the charge density and current density for the system. For scalar and pseudoscalar meson fields, this reduces to the expectation value of the space integral of the absolute square of the meson potential. Ambiguities in the sum rules arise because of the presence of divergent expressions. It is believed that these difficulties will be eliminated when charge renormalization and convergence techniques, such as the use of regulators, are applied. Applications of the results may be made to such processes as photo-production of mesons, scattering of gamma-rays by nucleons, Delbruck scattering, and pair production by gamma-rays.

WA8. Matrix Elements of Beta-Decay. HENRY BRYSK AND EUGENE GREULING, *Duke University.*—In the expression for the transition probability of beta-decay

$$1/\tau = (G^2/2\pi^3)\,|M|^2 f(Z, W_0),$$

the function $f(Z, W_0)$ of the electron-neutrino field has been investigated in detail and calculated for the various interactions. The nuclear matrix elements $|M|$, however, have heretofore only been very crudely estimated, because the wave functions of the many-body problem involved could not be determined. Under the one-particle nuclear shell model, the task becomes feasible. Using the Dirac representation, we have derived the wave functions for a nucleon in a square-well potential, and from them computed the matrix elements for all allowed and first-forbidden and some higher forbidden interactions. The results obtained differ considerably from the previous assumptions as to relative order of magnitude of terms, and contributions are found to so-called "*L*-forbidden" transitions, since *L* is not a good quantum number in the dirac representation. Interpretations of specific cases will be presented.

WA9. An Alpha-Particle Model for Be^8 and C^{12}. RICHARD R. HAEFNER, *University of Minnesota.*—The interaction of two alpha-particles is represented by a square-well potential with the addition of a potential q^2/r^2 for separations of the centers of the particles less than r_0, and a pure coulomb potential for greater separations. The well depth is chosen to give a $^1S_0$ virtual state at 90 kev, center-of-mass energy. A resonance for the $^1D_2$ state is found near 3 Mev for $r_0 = 4.5 \times 10^{-13}$ cm for $q^2 = 30\hbar^2/2\mu$. The extensions of this model to the Li^8 beta-decay show good agreement with the data of Bonner *et al.* on the resulting alpha-particle spectrum. The comparison of the cross sections for alpha-alpha-scattering from this model and those using the phase shifts determined by Wheeler from the experimental data are in fair agreement when account of the poor geometry and large energy spread of the actual experiments is taken into account. Experiments with improved geometry and better energy definition for alpha-particle laboratory energies 4–7 Mev might show the $^5S_0$ level at 2.8 Mev[1] to be non-existent. Owing to the symmetry requirements on the wave function for a rigid model with alpha-particles at the vertices of an equilateral triangle, the first excited state of C^{12} for this model has even parity and two units of angular momentum. Associating this level With the excited state of C^{12} at 4.47 Mev, experimental evidence applicable to it will be discussed.

WA10. The Interpretation of Isomeric Transitions. STEVEN A. MOSZKOWSKI, *Argonne National Laboratory.*—Graphs of the theoretical half-life energy relation for nuclear isomeric transitions according to the recently developed theory of Blatt and Weisskopf[1] are shown. According to this theory, many isomeric transitions can now be assigned to magnetic 2^4 pole radiation, consistent with predictions from the Mayer[2] shell model. There are a number of isomeric transitions with half-lives of 1 second to 1 hour, which cannot be caused by magnetic 2^4 pole radiation. A possible explanation of these transitions for odd-*A* nuclides is that one of the states involved in the transition has a spin determined by the coupling of several odd nucleons, rather than by one odd nucleon. On this assumption, the transitions might be expected to be electric 2^3 pole. These short-lived isomeric states occur exactly for those nuclides for which one would expect "many-particle" levels, according to the shell model. Some difficulties associated with this explanation will be discussed.

[1] J. M. Blatt and V. F. Weisskopf (privately circulated notes to appear as part of a book on nuclear physics).
[2] M. G. Mayer, Phys. Rev. 78, 16 (1950).

WA11. Quantum States of Aggregation. PETER FIREMAN, *Columbian Carbon Company.*—Light waves of high frequency in approaching a metallic surface negatively charged consolidate, as it were, and strike the surface like corpuscles, forcing the emission of electrons. Viewing the whole process with an open mind, it suggests that the discontinuous waves, in encountering the metal surface, aggregate more closely while colliding with the atoms of the metal. In other words, we are confronted with the phenomenon of the light waves passing from one state of aggregation (waves) to another (corpuscles). On the other hand, electrons, true corpuscles, greatly confined while being forced through gratings, spread out freely on issuing from the gratings and form diffraction patterns after the manner of waves; another play of change of state of aggregation.

WA12. Eccentric Circular Orbits. GERTRUDE SCHWARZMANN.—Interpreting all corpuscle motion as compounded motion,[1] the electron spinning about its spin axis is supposed to revolve in an eccentric circle about its nucleus. Each axis of a rectangular coordinate system, the nucleus in its origin, divides the eccentric circle into two semicircles. In the two equal semicircles, wavelength 7.3/v cm and frequency $v^2/7.3$ sec^{-1} are conjoint to *v*, velocity of electron *and* electron wave.[1] In each unequal semicircle the operations arc/pi, (sector/½pi)½, 2 sector/arc yield the radii r_1, r_2, r_3, respectively, to which are conjoint the velocities v_1, v_2, v_3, respectively, (r_2 geometrical mean between r_1 and r_3). The radius vector sweeps at the rate $\frac{1}{2}v_3 \cdot r_3$, during period $r_1\text{pi}/v_3$, over the sector, while the electron, spinning at frequency $v_1^2/7.3$, describes the wavelength $7.3/v_1$, if the ground orbit is considered, wherein each semicircumference equals one wavelength.[1] Motion in eccentric circular orbits fulfills exactly the laws of classical physics, if modified by quantum and relativity theory, if the third radius is interpreted as radius vector and the inert electron mass as quantity of motion, hf/mv^2.[1]

[1] G. Schwarzmann, Phys. Rev. 72, 536 (1947); 744 (1947); 73, 1273, 1274 (1948); 75, 1334 (1949).

SATURDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(W. F. G. SWANN presiding)

Counters and Counting Circuits

X1. Organic Scintillators.* R. C. SANGSTER† AND J. W. IRVINE, JR., *M.I.T.*—The scintillation-counting behavior and fluorescent spectra have been determined for a number of organic compounds from the homologous series based upon diphenyl, diphenylmethane, stilbene, and diphenylacetylene. The substances were carefully purified, primarily by adsorption and crystallization techniques. Fairly perfect, standardized crystals were prepared. Counting data were taken at 30°C and at −75°C using a Co-60 γ-ray source and an RCA C-7140 photo-multiplier. It is reproducible to within ±2 percent. In the given radiation field, a useful "efficiency" parameter is the discriminator voltage at which the counting rate has been reduced to one-half of that (extrapolated) for zero discrimination. The "phosphor absent" background parameter is less than 2 percent of that of anthracene. The parameters for different crystals of a given substance usually fall within ±3 percent of the mean value. Thermal coefficients range from slightly positive values to −3.5 percent per degree centigrade. Spectrographic data were obtained with an automatic-recording, grating spectrograph using a C-7140 photo-multiplier as the radiation detector. An attempt has been made to interpret the results to gain insight into the fundamental phenomena involved.

* The work described was supported in part by the AEC.
† AEC Predoctoral Fellow.

X2. Some Characteristics of Nonluminescent Cadmium Sulfide as a Gamma-Ray Counter. DAVID E. SOULE, *Northwestern University* (Introduced by J. H. ROBERTS).—Nonluminescent cadmium sulfide crystals with small internal strain and relatively large photo-conductivity exposed to radium gamma-rays were studied in a fast conduction counter circuit at room temperature. A negative space charge effect was observed resulting in a decrease of the count rate by a factor of about 6 and the crystal current by a factor of 1.26 during the total time of irradiation. An equilibrium value was reached after 2 to 3 hours. At this time the count rate increased linearly with increased applied potential (230 to 385 volts/cm). The differential pulse height distribution was approximately gaussian with a mean input pulse height greater than 36.5 microvolts and a root mean square deviation of 4.3 microvolts. An attempt is being made to fit a curve consisting of the theoretical count rate of secondary electrons *versus* their energy absorbed in the crystal (Compton effect contributing 95 percent of the total absorption for 1.8-Mev gamma-rays) to the above differential pulse height curve and to determine an approximate value for the schubweg.

X3. Pulse Height Spectrum Produced in NaI by Nuclear γ-Rays of Various Energies. W. M. GOOD, C. D. MOAK, G. P. ROBINSON, AND H. REESE, *Oak Ridge National Laboratory.*—Owing to its high efficiency and to its compactness, the NaI Scintillation Spectrometer has some obvious advantages over magnetic spectrometers for the study of γ-rays. The response of such a spectrometer to γ-rays of various energies is being studied by means of nuclear gamma-rays of known energies. The gamma-rays being studied include those from the reactions of $B^{11}+H^1 \rightarrow C^{12}+\gamma$ 16.70 Mev, $B^{11}+H^1 \rightarrow C^{12}+\gamma_1+12.12$ Mev $+\gamma_2+4.58$ Mev, $H^2+H^1 \rightarrow He^3+\gamma+5.48$ Mev, $H^2+H^1 \rightarrow He^4+\gamma+19.7$ Mev. The spectrometer is of the type described by others at ORNL[1] and consists of a NaI crystal, a multiplier tube, a linear amplifier and preamplifier, and a differential pulse height selector. At the present time, as the γ-ray energy gets higher, the spectra show a less and less well-defined peak in the pulse height spectrum corresponding to complete absorption of the positron, electron pair. At the moment, it is not clear that this is due to the size of the crystal.

[1] W. H. Jordan and P. R. Bell, Nucleonics **5**, 30 (1949).

X4. A Large Area Photo-Cathode Photo-Multiplier for Scintillation Counting.* P. W. DAVISON AND G. A. MORTON,† *R.C.A. Laboratories.*—A number of applications of scintillation counters require a large phosphor crystal or screen. If the phosphor is absorbing or nonreflective, efficient optical coupling can only be obtained if the areas of the screen and multiplier photo-cathode are comparable. For this reason a multiplier photo-tube has been developed having a photo-cathode with an area of 95 cm². The tube has a diameter of 2½ inches and an over-all length of 8 inches. The cathode covers 180° of the cylindrical wall and extends for about half the length of the tube. The multiplier unit has ten stages and a gain of 10^6 under normal operating conditions. The properties of the tube will be described. As an illustration of one application of the tube, its performance as an alpha-particle counter with a large sensitive screen will be discussed.

* Work done under Navy BuShips contract.

X5. Response of Scintillation Counters to Heavy Particles.* C. J. TAYLOR,** M. E. REMLEY, W. K. JENTSCHKE, AND P. G. KRUGER, *University of Illinois.*—The response of anthracene, stilbene, and sodium iodide crystals in a scintillation detector to the type and energy of heavy charged particles incident on the crystals has been investigated. Deuterons and molecular hydrogen ions with energies of 1 to 11 Mev, protons of 1 to 5 Mev, and alpha-particles of 4 to 21 Mev were used. Aluminum absorbing foils were placed in the cyclotron beam to obtain the various particle energies incident on the crystals. Pulses were amplified with a Los Alamos Model 100 amplifier and analyzed with a twelve-channel pulse amplitude analyzer. Essentially gaussian distributions with a full width at half-maximum of six to eight percent were obtained for the higher energy particles. With the exception of protons and deuterons in sodium iodide, which gave linear response, plots of pulse height *vs* energy gave a nonlinear relation over a certain low energy region with a linear response being indicated provided the energy of the particle is large enough. There are indications that this nonlinearity is dependent on the ionization density of the incident particle.

* Assisted by the joint program of the ONR and AEC.
** Now at North American Aviation, Inc.

X6. Response of Scintillation Counters to Electrons.* W. K. JENTSCHKE, C. J. TAYLOR,† M. E. REMLEY, F. S. EBY, AND P. G. KRUGER, *University of Illinois.*—The investigation described in the preceding paper was extended to a study of the response of anthracene and sodium iodide crystals to electrons. Electrons of energies from 500 ev to 624 kev were used. The lower energy electrons (500 to 5000 ev) were obtained from a pulsed electron gun, fabricated in a special cathode-ray tube in which current was measured with a vibrating reed electrometer. Pulse heights were measured visually and photographically on a high speed oscilloscope. Higher energy electrons were obtained from internal conversions in radioactive sources, and the pulses were analyzed with a twelve-channel pulse

amplitude analyzer. Pulse height *vs* energy curves for anthracene show a nonlinear response below 100 kev in agreement with Hopkins,[1] while the sodium iodide curve is essentially linear, agreeing with the work at Stanford.[2] The dependence of the response on ionization density of both electrons and heavy particles will be discussed.

* Assisted by joint program of the ONR and AEC.
† Now at North American Aviation, Inc.
[1] J. I. Hopkins, Rev. Sci. Instr. **22**, 29 (1951).
[2] West, Meyerhof, and Hofstadter, Phys. Rev. **81**, 141 (1951).

X7. A High Efficiency Detector for Fast Neutrons.* H. L. Poss, C. E. Falk, and Luke C. L. Yuan, *Brookhaven National Laboratory*.—The effectiveness of a liquid scintillator for detecting fast neutrons has been investigated. Terphenyl-xylene solutions[1] enclosed in glass cells of various lengths mounted on RCA 5819 photo-multipliers were used. Integral bias characteristics with sharp cutoffs were obtained. The ratio of maximum pulse heights of Co^{60} γ-rays (1.2 Mev), to ThC″ γ-rays (2.6 Mev), and to 14-Mev neutrons is 1:1.4:2.4. Absolute detection efficiency for neutrons was determined by counting the α-particles from the $H^3(d, n)He^4$ reaction serving as the neutron source.[2] Efficiencies ranging from 6 percent to 25 percent were obtained with counters $1\frac{1}{4}$″ in diameter and 1″ to 6″ long. The effects of the optical coupling and reflecting surfaces on the pulse height distributions will be discussed.

* Work done at Brookhaven National Laboratory under the auspices of the AEC.
[1] Reynolds, Harrison, and Salvini, Phys. Rev. **78**, 488 (1950). H. Kallmann and M. Furst, Phys. Rev. **79**, 857 (1950).
[2] Hanson, Taschek, and Williams, Revs. Modern Phys. **21**, 635 (1950).

X8. Fast Neutron Detection Using Scintillation Counters.* John H. Neiler, George E. Owen, and A. J. Allen, *University of Pittsburgh*.—Scintillation counters are being employed to detect fast neutrons with good efficiency. Preliminary experiments to determine the ratio of gamma-counting rates to fast neutron rates indicate that the gamma-ray background in the shielded scattering laboratory of the University of Pittsburgh Cyclotron Building are negligible. These results were obtained from lead and paraffin absorption experiments. The design and results of preliminary experiments for a fast neutron coincidence spectrometer will be presented. This design indicates that resolutions of approximately 3 to 6 percent can be obtained with 10^{-8} coincidence per unit neutron flux at 1 Mev.

* Assisted by the joint program of the ONR and AEC.

X9. Differential Coincidence Counting Method.* Z. Bay, *The George Washington University* (Introduced by R. R. Meijer).—The amplitudes of the output pulses of a coincidence circuit depend on the time delays between the input pulses. Hence, using two identical coincidence circuits, we can perform differential measurements which yield a more accurate determination of short times (e.g., 10^{-10} sec) than is obtained with a single coincidence circuit. We branch the channels coming from the two detectors and apply one branch of each channel to a first coincidence circuit and the other two with an inserted time delay to a second. The difference of the amplitudes of the output pulses will then be dependent on time delays of the original pulses. It can be positive or negative and is zero only in a short time interval, generally much shorter than the resolving time of the coincidence circuits. The difference-output can be used, e.g., to close a gate circuit for the output pulses from one of the coincidence circuits, thus narrowing its delay curve. Preliminary experiments show that the resolving time of a coincidence circuit can be improved, in this manner, by about one order of magnitude, without essential loss in sensitivity; and, therefore, this method seems to be superior to the shorted line technique.

* Supported by the ONR and AEC.

X10. An Experimental Study of Dead-Time Errors in Counting Particles from Pulsed Sources.* C. H. Westcott and J. S. Greenberg, *McGill University*.—Counting losses due to dead-time effects may become serious when instantaneous effects from a synchro-cyclotron or other pulsed-output accelerator are studied. For a single counting channel, these effects have been computed;[1] but when coincidence techniques are used, the calculation of the errors becomes quite involved. To check the published calculations and to extend our knowledge to errors expected for coincidence arrangements, the problem is being studied experimentally with scaled-up time intervals. Instead of microsecond or shorter pulses used with proportional or scintillation counters, we use a polonium source placed behind a rotating shutter to give random-spaced counts within a pulse of duration of the order of milliseconds, and dead-times of the same order are introduced electronically. Coincident events superimposed on a noncoincident background can be studied with a mixer arrangement. The results obtained to date will be discussed in relation to the program for coincidence arrangements. While primarily intended to guide work with the McGill cyclotron, the interest of the problem is general and its relation to work elsewhere will be reviewed.

* Work supported by the National Research Council of Canada.
[1] C. H. Westcott, Proc. Roy. Soc. (London) **A194**, 508 (1948).

X11. Current Time Relationships for Single and Multiple Centered* Geiger Counter Pulses.† W. E. Ramsey, *Bartol Research Foundation*.—These measurements focus on the region from 10^{-8} to 10^{-6} second. For argon—ether and argon—butane, the current is constant while the sheath is being established, then varies inversely as the time while it moves outward to the cathode. Current and spreading velocity are both proportional to overvoltage. All pulses initiated by a single electron at a point are identical throughout their life history. The initial current in multiple centered discharges indicates the number of centers except for overlapping due to the spreading process. An improved form of a circuit previously described,[1] was used for these studies.

* A discharge initiated by more than one electron in the gas.
† Assisted by the joint program of the ONR and AEC.
[1] W. E. Ramsey, Phys. Rev. **57**, 1022 (1940).

Saturday Afternoon at 2:00

NBS, East Building

(Eric Rodgers presiding)

General Physics

Y1. Equilibrium Ultracentrifuge.* J. D. Ross, A. Robeson, and J. W. Beams, *University of Virginia*.—The ultracentrifuge rotor is suspended magnetically in a brass vacuum chamber (pressure less than 10^{-5} mm Hg). It is driven to running speed by an air turbine below the vacuum chamber which is connected to the rotor by a small shaft along the axis of rotation.

The shaft passes through vacuumtight oil glands in the chamber and is disconnected from the rotor when it attains operating speed. During the sedimentation experiment the rotor coasts freely and decelerates less than 0.1 revolution per sec per hour. Consequently, the rotor is free of "hunting," and its speed can be precisely determined. Also, since there is no shaft, the temperature is maintained at a known constant value by thermostating the chamber. The rotor is constructed of steel and Duralumin ST-14. It weighs 4.9 kg, and the center of the standard centrifuge cell is 65 mm from the axis of rotation. So far, schlieren methods have been used for measuring the concentration gradients in the cell, but a more precise interferometer method is under development. Although the apparatus was designed for determining molecular weights by the equilibrium method, it also may be used for the rate of sedimentation method.

* Supported by Navy Bureau of Ordnance, Contract NOrd-7873.

Y2. Electron Optical Field Mapping. A. VANBRONKHORST, L. MARTON, AND S. B. GARFINKEL, *National Bureau of Standards.*—In continuation of the study of quantitative measurements of small magnetic fields by the electron-optical shadow method,[1] it became desirable to determine empirically shadow deflection distance as a function of field strength. The basis of this investigation is the direct measurement, in the "equatorial" plane, of a magnetic field which has a high gradient and is of small enough physical dimensions to be viewed by a high resolution electron optical system. For this purpose a small electromagnet was made having spade-shaped pole pieces and a gap width variable from 0.05 to 0.025 inch. Using a rotating coil the field of this magnet was directly measured to an accuracy of ±0.2 gauss. Under the assumption of small electron deflection angles, an empirical relation between shadow deflection distance and field strength can be established. This serves as an independent check on any theoretical determination of deflection *vs* field strength.

[1] J. Appl. Phys. **20**, 1258 (1949).

Y3. Electron Optical Bench. L. MARTON, M. M. MORGAN, D. C. SCHUBERT, J. R. SHAH, AND J. A. SIMPSON, *National Bureau of Standards.*—An electron optical bench has been built capable of utilizing up to three electron lenses and four independently adjustable apertures or test objects. All the lenses and apertures or test objects can be aligned and displaced with three degrees of freedom by means of controls located outside the vacuum system. Up to the present time the electron optical bench has been used exclusively for measurement of the optical constants of magnetic electron lenses. The accuracy obtained in preliminary measurements of focal length is discussed, as well as possible improvements in design and operation.

Y4. Dielectric Constants of Various Gases for 9470 Mc.* CLAYTON M. ZIEMAN, *Wabash College.*—Cavity comparator methods and a microwave refractometer[1] were used to measure the dielectric constants of dry air, O_2, H_2, CO_2, and dry air mixed with SO_2 for 9470 Mc and pressures from 2 up to 740 mm Hg. The results for dry air, O_2, and CO_2 agree closely with recently published values;[2] a tentative S.T.P. value of $(\epsilon-1)\times10^4$ for H_2 is 3.56. For dry air of partial pressure 634 mm Hg contaminated with various amounts of SO_2 of partial pressures 20 to 100 mm Hg, $(\epsilon-1)\times10^4$ increases from 4.36 to 5.43 at 25°C.

* Research supported by Research Corporation.
[1] George Birnbaum, Rev. Sci. Instr. **21**, 169 (1950).
[2] Birnbaum, Kryder, and Lyons, J. Appl. Phys. **22**, 95 (1951).

Y5. A High Speed Magnetic Storage System for Parallel Digital Computers. DONALD H. JACOBS AND MICHAEL MAY, *The Jacobs Instrument Company.*—The extremely high computing speeds which all-parallel computers can attain require a storage medium of correspondingly high speed. Such a medium must (for practical reasons) be very compact, very reliable, and consume very little power, in addition to having a short access time. A register satisfying these requirements has been constructed using small magnetic cores and new circuit techniques. This type of register is different in theory and use from the various magnetic storage devices developed for use with serial computers. This type of register employs one core of a nickel-iron oriented alloy per stored digit. This core is ¼" in diameter and ¼" wide, and is fabricated of 0.0004" thick tape. The register is of the parallel type, and all its contents can be transferred out in 2–4 microseconds. The register is very small and requires very little power. It comprises one core per digit, plus five subminiature tubes. These five tubes suffice for registers holding up to 40 digits. The register can transfer its contents into another register without the use of any auxiliary circuits. Each core is used to control a gate through which a transfer pulse passes, or not, depending on the state of magnetization of the core.

Y6. Maximum Safe Amplitude of Several Simple Mechanical Systems Vibrating at Resonant Frequency. PRESTON B. CARWILE, *Raytheon Manufacturing Company.*—Derivations are given for several simple bodies (slender bars and thin plates) and different types of vibration, under the condition that the tensile stress may not exceed the endurance limit at any point in the body. Among the cases treated is an unpublished study by Dr. Carlo Calosi of a circular plate of tapered thickness. A comparison of the results show that in the few cases treated and for a fixed resonant frequency, longitudinal resonance offers greater safe amplitude than flexural resonance. Furthermore, longitudinal resonance of an exponentially tapered bar offers the possibility of safe amplitude in excess of that ordinarily considered possible in either a uniform bar or plate of the same material.

Y7. On Polarization in Conductance Phenomena.* GEORGE JAFFE, *Louisiana State University.*—A theory of polarization in conducting media has been previously developed by the author based on the concept that some of the carriers are unable to discharge at the electrodes. The strong effects of polarization in crystals and semiconductors can thereby be explained quantitatively.[1] The theory may be extended to liquid media, electrolytes, and dielectrics, if it is assumed that the rate of discharge is proportional to the concentration of the relevant carriers at the boundary. The amount of polarization and the currents will depend on the ratio of the "discharge constant" to the diffusivity. The theory has been generalized in this direction for direct and for alternating applied voltages. Measurements on electrolytes were carried out under conditions where polarization effects are predominant, i.e., between parallel plates of relatively large area and small distance. The equivalent series resistances and capacitances were measured under varying conditions of frequency, concentration and plate distance. The results are in quantitative agreement with theory; however, it is necessary to assume a group of ions of unusually low mobility to account for the high values of capacitances observed (several microfarads per cm^2), and their frequency dependence.

* Work supported in its later phases by ONR.
[1] George Jaffe, Ann. Physik **16**, 217–284 (1933). Final Report, Signal Corps Project 152 B.

Y8. A Concept of Active Surface. J. G. BARREDO, *University of Chicago.*—By using an oscillograph, it has been possible to record the polarization current of an electrode immersed in 1*N* KMO_4 and 0.1*N* NaOH solution. The increase in polarization and subsequent decrease in current passed by the electrode is recorded as function of time over a period of 1/250 sec. Using those data, and knowing the current in the static state of the system, it has been possible to define a new concept of

surface as follows:

$$\Sigma = K^{1/n} F^{-1} I^{1-1/n} t^{-1/n},$$

in which Σ is the value of the active surface of the electrode, F the faraday, I the current, t the time, K a constant, and n the number of particles which produce the elemental reaction over the electrode. This concept of surface embraces as a particular case the geometrical concept of surface, where all the points of the surface are equally active.

Y9. On Fluctuations in Thermodynamic Intensive Parameters.* RICHARD F. GREENE† AND HERBERT B. CALLEN, *University of Pennsylvania.*—The fluctuations in thermodynamic intensive parameters ("generalized forces") have relevance to the theory of linear irreversible processes, as well as having direct application to the description of thermodynamic equlibrium. The conventional statistical mechanical definition of the intensive parameters, however, is such that these parameters are rigorously constant and not subject to fluctuation. Despite this, the possibility of fluctuation is indicated by the intuitive notion of temperature, pressure, etc.; and, an analysis of the operational meaning commonly attached to these concepts requires that they be defined in such a way as to be capable of fluctuation. We have introduced a definition of the intensive parameters which is appropriate in this respect, and have computed the moments of the fluctuations of these parameters.

* Assisted in part by the ONR.
† John F. Frazer Fellow.

Y10. A New Interpretation of Entropy. MAX SOLOW.—The importance of entropy in thermodynamics and statistical mechanics cannot be overemphasized. The concept of entropy resulted from empirical considerations.[1] Using a method developed in communication theory,[2,3] the quantity $H = -\Sigma_i P_i \log_2 P_i$ can be interpreted for any ensemble as the average number of binary digits, b, necessary to designate a gross event with the probability P_i. From group theory b represents the degrees of freedom. Since this interpretation is true for all ensembles, it is true for H in statistical mechanics, hence for entropy in thermodynamics, and for H in information theory.[3] Thus, entropy is related to the complexity of an ensemble; biological systems can be ordered according to complexity and hence entropy. For irreversible processes the entropy of the universe increases and it becomes more complex. Thus, time is irreversible: its positive direction results in increasing complexity. From communication theory[3] the uncertainty of any experiment is caused by the degrees of freedom occupied by the observing mechanisms; thus nature is not necessarily uncertain.

[1] K. K. Darrow, Memorial to the classical statistics, Bell System Tech. J. **22**, 108–135 (January, 1943).
[2] C. E. Shannon, *The Mathematical Theory of Communication* (The University of Illinois Press, Urbana, 1949).
[3] R. M. Fano, "The transmission of information," Research Lab. of Electronics, M.I.T., Tech. Rpt. 65.

Y11. Thermodynamics of Material Systems: a Theory of Catalysis. J. L. FINCK, *The J. L. Finck Laboratories.*—This paper is a continuation of the previous work of the author on thermodynamics.[1] Utilizing the concept of a *complete* system, which requires the complete definition of a system by n independent variables, the author points out that among these independent variables may be those describing the chemical composition, the degrees of transformation among the phases of the system, the degrees to which chemical reactions have taken place, and also quantities such as mechanical stress, electric and magnetic field intensities, and density. The velocity is also considered in that it enters the kinetic energy. All types of metastable states are included. An equation for the continuity of energy of a complete system is developed, and the concepts of isotropy and homogeneity are applied to the considerations of the activity of the system. The concept of boundaries is generalized, and this leads directly to a logical theory of catalysis. It is shown that there may be mechanical, electric, chemical, phase, and other types of boundaries: in fact, for a complete system there are n types of boundaries. For each boundary a gradient may exist which if not zero will excite activity involving a change of energy with time. It is therefore the function of heterogeneous catalysts, say, to introduce such gradients in the system. The concept of equilibrium is elaborated on, and it is shown that Guldberg and Waage's law of mass-action is but a very restricted and approximate statement of what actually occurs in the activity of a system. States in thermodynamic equilibrium are considered, and some relations are developed for systems in several phases and of one or more chemical components.

[1] J. Franklin Inst. **245**, No. 4 (April, 1948); also, **245**, No. 5 (May, 1948).

SATURDAY AFTERNOON AT 2:00

Shoreham, Terrace Room

(H. H. NIELSEN presiding)

Optical Spectroscopy

Z1. On a Modification of the Eagle Diffraction Grating Mounting. HARRY S. ROBERTSON AND JEAN A. POTVIN, *University of Miami.*—The conventional Eagle spectrograph mounting has among its advantages compactness and a wide wavelength range. As usually constructed, however, three independent adjustments (grating rotation, plate rotation, and distance from grating to slit) are necessary in order to change the range of the instrument. In addition, conversion from photographic to photoelectric recording is, at best, awkward. A simple coupling mechanism in the modified instrument automatically rotates the grating and the plate holder as the grating is moved along the axis, thereby reducing the number of controls to one, but leaving the instrument optically equivalent to the Eagle. The plate holder may now be replaced by a photo-tube, fixed to look always at the grating. Thus, if the lead screw governing the slit-to-grating distance be motor driven, the photo-tube may be set to scan the desired spectral range. As a final feature, a servomechanism can easily be devised, such that the recorder plots wavelength linearly.

Z2. Fine Structure in Some Infrared Bands of Methylene Halides. EARLE K. PLYLER AND W. S. BENEDICT, *National Bureau of Standards.*—The infrared absorption of CH_2ClBr, CH_2ClBr, and CH_2Br_2 has been studied with a high resolution grating spectrometer in the region 16–2.3 u. Using the saturated vapor in a cell 60 cm long, it was possible to resolve the fine structure corresponding to rotation about the least axis of inertia in three to five bands of each molecule. The resolved bands all are overtones and combinations of fundamental vibrations localized in the methylene radical, and hence ap-

pear at nearly the same frequencies for each molecule, and show no detectable isotope shift. Bands with Q branches (type C, B, symmetry) and without that feature (type B, A, symmetry) both appear. Application of combination relations to all bands of a given molecule yield rotational spacings of the ground state agreeing within 0.5 percent. The spacings, $[A''-(B''-C'')/2]$, are, respectively, for CH_2Cl_2, 0.961 cm^{-1}; CH_2ClBr, 0.902 cm^{-1}; and CH_2Br_2, 0826 cm^{-1}. The molecular dimensions cannot be uniquely determined from these data alone; but if tetrahedral angles are assumed, they lead to improbably low values of the C-Halogen distance, namely 1.69A for C-Cl and 1.82A for C-Br. If the Halogen-C-Halogen angle is increased to 112°, as found by electro diffraction,[1] the C-Cl distance is in perfect agreement with the electron diffraction value 1.759A, and C-Br becomes 1.899A in CH_2Br_2 and 1.906A in CH_2ClBr.

[1] L. O. Brockway, J. Phys. Chem. **41**, 747 (1937).

Z3. Bands of C_2 and CN in Infrared Flame Spectra.* W. S. Benedict and Earle K. Plyler, *National Bureau of Standards.*—In the inner cone of the oxy-acetylene flame, as observed under high resolution using a 15,000-line grating spectrometer and lead sulfide cell, several bands appear between 1μ and 1.6μ. These have been identified as the (1, 0), (0, 0), and (0, 1) bands of the Phillips system of C_2 ($^1\Pi_u - {}^1\Sigma_g^+$), with origins at 9852, 8268, and 6441 cm^{-1}, and the (0, 0) and (1, 1) bands of the red system of CN ($^2\Pi - {}^2\Sigma$), with origins at 9117 and 8862 cm^{-1}. The rotational structure of the C_2 bands shows an intensity distribution characteristic of thermal equilibrium with an effective temperature near 2400°K.

* Supported in part by ONR.

Z4. The Infrared Dispersion of C_2H_2. R. L. Kelly, R. Rollefson, and B. Schurin, *University of Wisconsin.*—The index of refraction of C_2H_2 has been measured for wavelengths between 1 micron and 18 microns by the method described previously.[1] A dispersion formula has been found which fits the observed data in the visible and infrared regions, including the formula of Watson and Ramaswamy.[2] The dispersion formula contains the integrated absorption coefficient for the strong vibration-rotation bands. An interpretation of the results in terms of C−H bond moment is being attempted.

[1] R. Rollefson and R. Havens, Phys. Rev. **57**, 710 (1940).
[2] H. E. Watson and K. L. Ramaswamy, Proc. Roy. Soc. (London) **156A**, 144 (1936).

Z5. High Dispersion Measurements on ω_3 of $C^{14}O_2^{16}$ at 4.5μ. Alvin H. Nielsen and Robert T. Lagemann,* *The University of Tennessee† and Oak Ridge National Laboratory.*—A preliminary report on measurements currently being made on the infrared vibration-rotation spectrum of $C^{14}O_2^{16}$ will be given. Thus far, the fundamental, ω_3, has been resolved and its rotation-line frequencies determined. A prism-grating spectrometer utilizing a rocksalt monochromator and a 7200 lines-per-inch grating was employed in this investigation. The $C^{14}O_2^{16}$, made from 4.2 percent enriched $BaCO_3$, was contained at a pressure of 14 cm of mercury in an 8-cm long glass cell closed with rocksalt windows. Combination relations have been applied to the data and values of B_{000}, B_{001}, α_3, and the band center have been obtained. The expressions for the anharmonic constants X_{13}, X_{23}, X_{33} together with ω_3 as given by Dennison[1] have been adjusted with the appropriate reduced mass factor. Satisfactory agreement is achieved between the observed and calculated values of the constants.

* Emory University.
† A Frederick Gardner Cottrell Grant-in-Aid is gratefully acknowledged.
[1] D. M. Dennison, Revs. Modern Phys. **12**, 175 (1940).

Z6. Comparison of the Near Ultraviolet Absorption Spectrum in the Gaseous State and in Solution for Benzene and Substituted Benzenes.* Carl A. Beck and Brother Bernard J. Jansen, S.M., *Catholic University of America.*—A study of the broadening effect in solution spectra is given for the electronic transition around 2600A for benzene, toluene, phenol, monochlorobenzene, and aniline. Assuming the same ratios of intensities in vapor as in solution respectively, the various vapor bands are broadened by giving each the same half-intensity breadth and the same percentage asymmetry. They are then added. Then, the resultant curve after shifting to the red, agrees reasonably well with that in solution. Results show that the broadening and shift is dependent only on the electronic transition, the kind of molecule and solvent.

* Aided by ONR contract.

Z7. Fluorescence of Benzotrifluoride and Para-Xylene in the Near Ultraviolet.* Mantrala L. N. Sastri and H. Sponer, *Duke University.*—The ultraviolet fluorescence spectra of benzotrifluoride and para-xylene were investigated in the vapor phase by using condensed sparks from Sn, Mn, Fe, and a mercury arc as exciting light sources. Excitation was chiefly into the strong absorption regions of a few main bands. Corning glass filters and organic filters were used to cut off the short wavelength end of the spark spectrum. Pressures varied from 1–20 mm Hg so that the spectra obtained represent "high pressure" fluorescence. It extends from 2640–2925A in benzotrifluoride and from 2620–3150A in p-xylene. The spectra were photographed in a medium Bausch and Lomb quartz spectrograph. The analysis is in agreement with that of the corresponding absorption spectra. Observed prominent ground state fundamental vibrations are for benzotrifluoride: 141, 338, 623, 1004 cm^{-1}; and for para-xylene: 388, 458, 648, 829, 1208 cm^{-1}. They occur in progressions and combinations.

* Supported by the ONR.

Z8. Calculation of Electronic Levels in Pyridine and the Isomeric Picolines.* Gertrud P. Nordheim[1] and H. Sponer, *Duke University.*—The molecular orbital method as first described by Wheland and Pauling[2] was used for calculating electronic levels in pyridine and the picolines. The change in charge distribution of the benzene ring caused by the nitrogen atom in pyridine is treated by introducing into the secular matrix a perturbation parameter δ_1, at the position of the N-atom and smaller perturbations $\delta_2 = \delta_6$ in the neighboring positions 2 and 6 of the ring. In the isomeric picolines an additional perturbation δ_3 is introduced in the appropriate position of the secular determinant. Bonding and anti-bonding single electron molecular orbitals were calculated and the transitions determined to the lowest excited levels. They are of symmetry B_1 and A_1. This level scheme is incomplete because the $2sp^2$ electrons of the nitrogen atom have not been included in the calculation. Also, the overlap integral has been neglected. The theoretical results will be compared with experimental values.

* Supported by the ONR.
[1] Died in 1949.
[2] G. W. Wheland and L. Pauling, J. Am. Chem. Soc. **57**, 2086 (1935).

Z9. Calculation of Electronic Levels in Pyridine and the Isomeric Picolines Including Overlap.* P. O. Löwdin and H. Sponer, *Duke University.*—Pyridine and the isomeric picolines have been treated by the semi-empirical molecular orbital method described in the foregoing abstract, but now the overlap integrals have been included according to a method developed by one of us.[1] Not only the energy levels but even the charge densities are affected by the overlap. The theoretical results will be compared with experimental experience.

* Supported by the ONR.
[1] P. O. Löwdin, J. Chem. Phys. **18**, 365 (1950).

Z10. Absorption Studies of the Vapors of the Isomeric Picolines in the Near Ultraviolet.* Joseph H. Rush† and

H. SPONER, *Duke University*.—Studies of the near ultraviolet absorption spectra of α-, β-, and γ-picoline vapor have been made in low and medium dispersion. Conclusive evidence is found for two electronic transitions in the vicinities of 35,500 and 38,500 cm^{-1}. The former transition gives rise to a system I of sharp bands resembling the spectrum of pyridine in the same region; the latter is represented by a diffuse system II, which resembles the spectra of some substituted benzenes and lies in the same region as the benzene group. The intensity of the diffuse system is markedly higher than that of the sharp system. Both systems exhibit the characteristics of allowed transitions. The diffuse system in β-picoline presents features which suggest superposition of still another system. The analysis of the spectra will be presented and the assignment of the electronic levels discussed. There is in pyridine the possibility of electronic states, in addition to those analogous to the benzene states, which may arise from the presence of nitrogen in the pyridine ring.

* Supported by the ONR.
† Present address: High Altitude Observatory of Harvard University and University of Colorado, Boulder, Colorado.

Z11. A Comparison of the Near Ultraviolet Absorption Spectra of Some Pyridine Derivatives in Various Solvents.* HAROLD P. STEPHENSON,† *Duke University* (Introduced by H. SPONER).—The near ultraviolet absorption spectra of picolinic acid, nicotinic acid, isonicotinic acid, α-picoline, β-picoline, γ-picoline, and α-chloropyridine have been measured in liquid solutions. It was observed that different solvents had different effects on the electronic transitions in the spectral region 2200–3000A. A Beckman Model DU spectrophotometer was used throughout to measure the following solutions: picolinic acid, nicotinic acid, and isonicotinic acid in water; α-picoline, β-picoline, γ-picoline, and α-chloropyridine in isooctane; all the compounds in 95 percent ethyl alcohol; and isonicotinic acid in 95 percent ethyl alcohol-water mixtures. Extinction coefficients ε have been calculated and have been used for a graphical determination of the oscillator strengths (*f* factors). α-chloropyridine shows anomalous behavior which apparently is related to chemical instability. Tables of results and graphs of the spectra will be presented and discussed.

* In part supported by the ONR.
† Shell Oil Company Fellow.

Post-Deadline Papers, if Any

SUPPLEMENTARY PROGRAMME

SP1. Cross Sections in the Feynman Quantum Electrodynamics.* MURRAY PESHKIN,† *Cornell University*.—The relation between cross sections and *S* matrix elements in the Feynman quantum electrodynamics follows from the equivalence of Feynman's formulation to the "standard" theory. An alternative approach, based on a familiar theorem from optics, is to normalize the scattering amplitudes by observing that the diagonal elements of S_{ba} are simply related to the total cross sections σ_a. This statement is identical to conservation of probability. To find the total cross section for an event to the lowest order in which it occurs, one writes down the *S* matrix element for the "closed" Feynman diagram, which consists of the original diagram joined to its reflection in the plane t=const. The expressions obtained converge except for infrared terms, and lead directly to invariant expressions for the cross sections. An explicit recipe will be given. This method has an interesting application to meson theories, where it is possible to limit the possible interaction forms directly from the *S* matrix by requiring that they must lead to positive cross sections. This criterion is analogous to the requirement of hermitian operators in order to obtain real eigenvalues in ordinary wave mechanics.

* To be given at the end of Session QA if time permits.
† Now at Northwestern University. This research was supported by the AEC predoctoral fellowship program.

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Stanford, George S. and Henry E. Duckworth—RA2
Steffen, R. M. and D. M. Roberts—Q3
Stephenson, Harold P.—Z11
Stokes, Richard H.—SA11
Storm, Martin L.—QA14
Sun, K.-H., F. A. Pecjak, B. Jennings, A. J. Allen and J. F. Nechaj—J12
Sunyar, A. W. and M. Goldhaber—K10
Swann, C. P. and C. E. Mandeville—J9
Taylor, C. J., M. E. Remley, W. K. Jentschke, and P. G. Kruger—X5
Thomas, L. H.—U2, W12
Thompson, R. W., Hans O. Cohn, and R. S. Flum—A5
Ting, Yu, Thomas L. Weatherly, and Dudley Williams—H4
Tobolsky, A. V.—EA1
Tomboulian, D. H. and R. W. Johnston—N4
Tomlinson, E. P., H. W. Fulbright, and J. J. Howland, Jr.—Q7
Toops, Edward C., Frederick E. Steigert, and Milo B. Sampson—J7
Trees, R. E.—QA12
VanBronkhorst, A., L. Marton, and S. B. Garfinkel—Y2
Van Patter, D. M., A. Sperduto, and H. Enge—J10
Verbrugge, Frank and Robert L. Henry—H11
Vidale, M. and Marcel Schein—A2
Vreeland, John A. and Kiyoshi Murakawa—RA7
Walker, R. L. and R. B. Day—D10
Weir, C. E.—E3
Welton, T. A.—T3
Westcott, C. H. and J. S. Greenberg—X10
Wheeler, J. A. and D. L. Hill—U3
Williamson, R. M., C. P. Browne, D. J. Donahue, D. S. Craig and K. W. Jones—D8
Witmer, Enos E.—RA4
Work, Richard N.—E6
Yadoff, Oleg—N12
Yevick, George—W6
Yu, Ming Chen W. and Eugene Guth—M13
Zaffarano, D. J. and F. I. Boley—Q8
Zieman, Clayton M.—Y4
Zimmerman, E. J. and P. G. Kruger—M7
Zmuda, Alfred Joseph—B3

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